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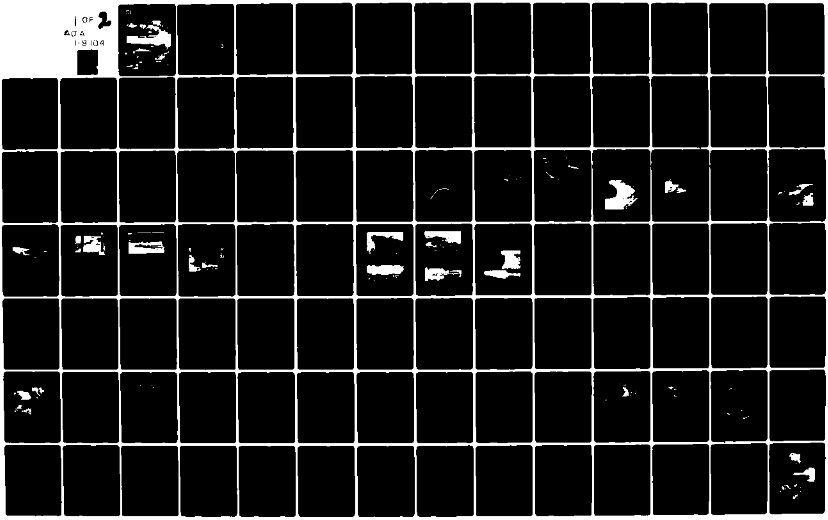

US Army Corps of Engineers

December 1981

THE STREAMBANK EROSION CONTROL EVALUATION AND DEMONSTRATION ACT OF 1974
SECTION 32, PUBLIC LAW 93-251

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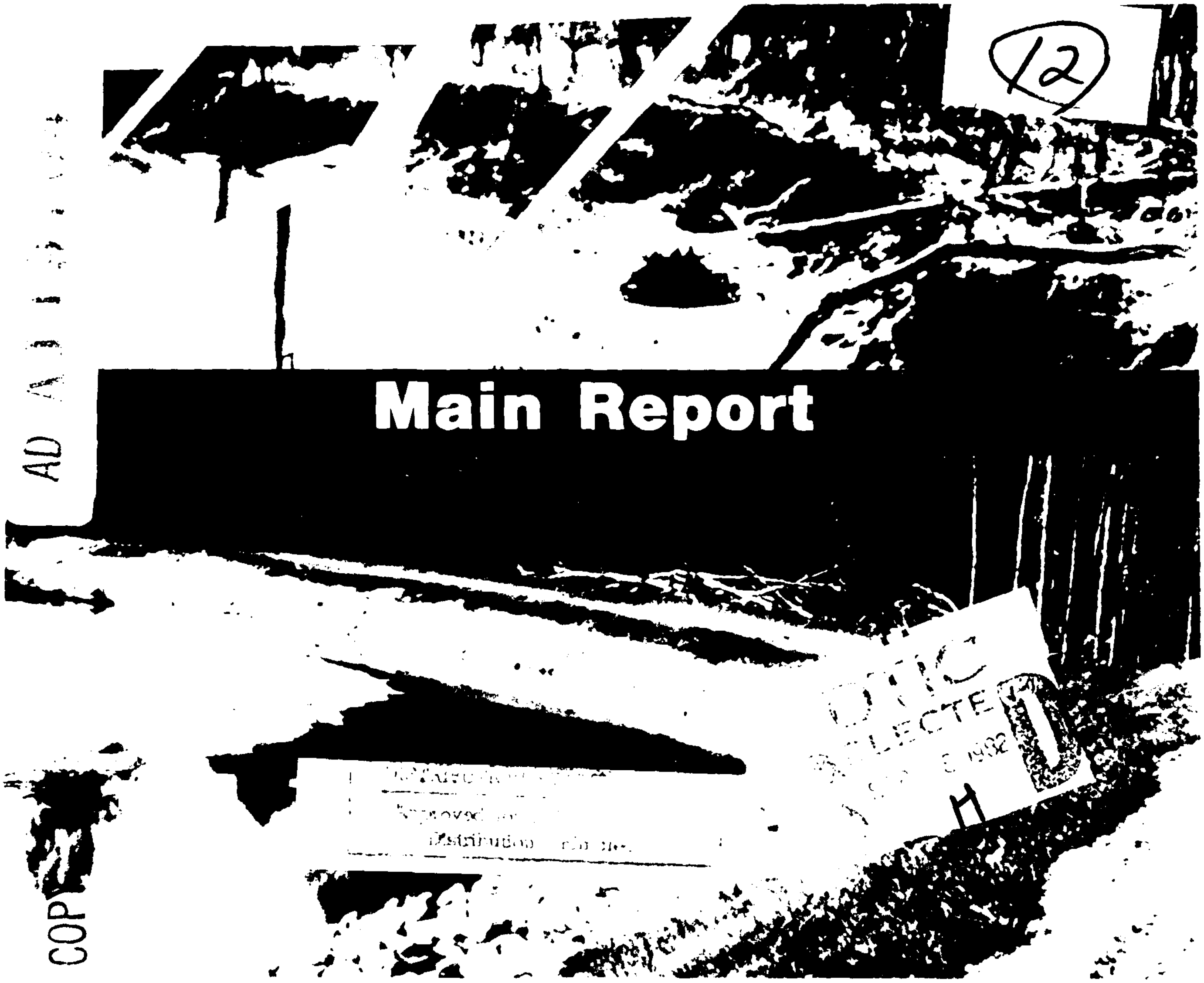

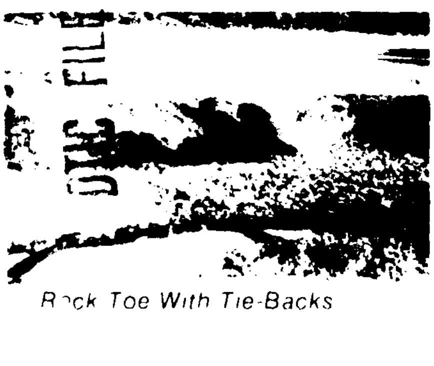
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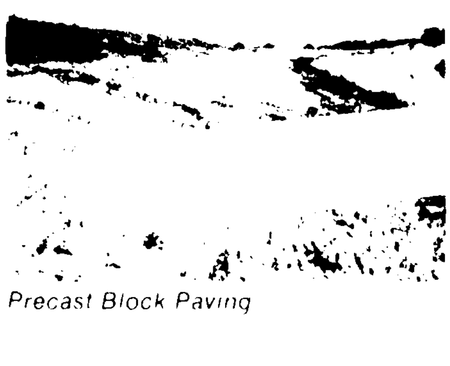
Precast Block Paving


Board Fence Dikes

FINAL REPORT TO CONGRESS

THE STREAMBANK EROSION CONTROL EVALUATION AND DEMONSTRATION ACT OF 1974 SECTION 32, PUBLIC LAW 93-251

MAIN REPORT

Supplemented by

APPENDICES A-H IN SEPARATE VOLUMES

U.S. ARMY CORPS OF ENGINEERS
December 1981

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic feet per second	0.02831685	cubic metres per second
feet	0.3048	metres
feet per second	0.3048	metres per second
inches	25.4	millimetres
miles (U. S. statute)	1.609344	kilometres
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square metres
square miles (U. S. statute)	2.589988	square kilometres

FINAL REPORT TO CONGRESS

Streambank Erosion Control Evaluation and Demonstration Act of 1974 Section 32, Public Law 93-251

EXECUTIVE SUMMARY

The Streambank Erosion Control Evaluation and Demonstration Act of 1974 (Section 32 of Public Law 93-251) was enacted in recognition of the serious economic losses occurring throughout the Nation due to streambank erosion. The Act, as amended, authorized $50 million for a national streambank erosion prevention and control demonstration program. This program consists of an evaluation of the extent of streambank erosion, nationwide; a literature survey and evaluation of bank protection methods; hydraulic research on effectiveness of bank protection methods; research on soil stability and identification of causes of streambank erosion; demonstration projects; and reports to the Congress. The term "streambank erosion" as used in this report generally includes bank-line damage occurring from sloughing, degradation of the bed, head-cutting, and failure by collapse as well as erosion. See PARTS VII and XVI of this Final Report for further explanation and definition of these terms.

The principal components of the Section 32 Program are research, construction, and technology transfer. Although the results of the research efforts are valuable and some of the research findings have been incorporated into the design of innovative techniques, the Section 32 Program focused primarily on construction of demonstration projects. Ninety percent of the program's funding covered construction, monitoring, and rehabilitation of the streambank erosion control demonstration projects. The demonstration projects reflect a variety of geographic and environmental conditions, including streams with naturally occurring erosion problems and streams with erosion caused or increased by man-made structures or activities. Much was learned under the Section 32 Program, but financial and time restrictions did not allow a more definitive analysis of the demonstration projects. The Demonstration Act was enacted to obtain information on costs and performance of several different methods of controlling streambank erosion. Therefore, all techniques were not expected to have the same level of performance. Depending on the value of property being protected, the cost-effectiveness of some techniques may prove acceptable while others will not. In all streambank erosion control projects the local sponsor must make this determination since they have the responsibility for continuing operation and maintenance. All demonstration projects are scheduled for abandonment or transfer to the local sponsor by September 30, 1982.

This report constitutes the largest item under the technology transfer activity and updates and expands the Interim Report dated September 30, 1978. A pamphlet written in nontechnical language will be available for public dissemination in the autumn of 1982. Other "lessons learned" will be incorporated in the technical design guidance materials.

Numerous benefits and knowledge have accrued from the demonstration program which included protection of some 125 bank-miles of eroding bank line at 68 legislated and selected demonstration projects, extensive literature surveys, observation of 50 existing works, laboratory investigations, and coordination with other Federal and non-Federal agencies. A

principal lesson learned from the program is that there is no universal method that offers low-cost bank protection for the situations encountered in the field. Effective erosion control on the main streams and tributaries will require careful planning, design, construction, and maintenance of the facilities provided. This will be expensive. However, results so far indicate that in some cases lesser amounts of erosion-resistant materials may provide reasonably effective streambank control. Also, various new methods can provide short-term, low-cost, do-it-yourself methods of streambank protection for smaller streams.

An equally important lesson is understanding the geotechnical characteristics of the site and the behavior of the stream throughout the basin and in the local reach. Effective protection may involve special attention to bed degradation, grade control, toe protection, upper bank seepage, and other factors relating to bank instability as well as to removal of the bank material by flowing water. On streams where bank instability can be attributed to bed degradation, grade-control structures may solve the bank caving problems and allow the banks to regain stability. Another major conclusion is that much erosion can be prevented by toe protection, especially with vegetation on the upper slope, in lieu of construction to the top of the streambank. Several erosion control techniques successfully demonstrated their ability to minimize their impact on the environment, and even potentially increase habitat diversity.

A wide range of geotechnical and hydraulic conditions, failure mechanisms, protective techniques, and materials are represented among the demonstration and existing projects. Substantial emphasis was placed on local availability of materials, ease of construction, and economy. The construction of the demonstration projects was accomplished generally by private contractors under contract with the Corps of Engineers. Labor costs by this construction method are high. However, a number of protection methods require only commonly available equipment. If constructed by do-it-yourself or readily available labor forces, costs could be considerably less than those indicated.

The major limitation of the streambank erosion control demonstration and evaluation program was the lack of an adequate monitoring period for many of the demonstration projects located on numerous streams and rivers throughout the United States. Much was learned at the demonstration projects where the monitoring program was in existence for several years and a critical flood event occurred to adequately test the soundness of the techniques. However, at some sites, not even a moderate flow has been experienced. At other demonstration sites, construction was not completed until the last year of the program and project effectiveness has not been determined. Offsetting this limitation to some degree was the evaluation of existing projects. Though not nearly as detailed as for the demonstration projects, it greatly enhanced the Section 32 Program because of the variety of stream parameters and the longer time period of their exposure to natural conditions. Selected demonstration projects will be periodically observed to further ascertain the effectiveness and longevity of the material or technique.

In addition to this report, technical design guidance is being prepared for Corps of Engineers offices, other engineering organizations, and the public. The guidance for public use is being written in nontechnical language and describes various methods of streambank erosion control from which locally favorable alternatives may be selected for consideration. Professional engineering and construction advice will usually be necessary to assure reliable performance under specific site conditions.

Details on the results and conclusions of each part of the program are described in the various parts of this report.

PART I: CONCLUSIONS

The following general conclusions have been formulated from the Section 32 Program. A large number of significant, but more specific, observations and conclusions are presented in the main report and its appendices.

Streambank erosion continues to be a serious problem along many of the Nation's streams and waterways, resulting in serious economic losses of private and public lands, bridges, etc. Approximately 142,000 bank-miles of our Nation's streams and waterways are in need of erosion protection. Treatment costs to arrest this erosion are estimated to be in excess of $1 billion annually. Costs of conventional bank protection methods currently available generally exceed the benefits derived by a large margin, thereby rendering the control of these areas uneconomical from a cost benefit standpoint. As a result, most erosion losses are continuing uncontested, and attempts to halt the erosion are limited to piecemeal-type protection works at isolated locations. However, the widespread concern about streambank erosion is reflected in the extensive amount of published literature and numerous current investigations of specific streams and problems throughout the Nation.

The causes of streambank erosion are complex and varied. Involved are streamflow characteristics, streambank and streambed stability, and the effects of man's activities. Erosion causes on major rivers may bear little resemblance to those on small streams. Streambank erosion causes frequently differ for various locations along the same river. In most instances, erosion at a site is the result of several causes. Recognition that each cause may require a specific cure is an important element when considering potential erosion control solutions.

The investigations of bank failure problems should extend beyond the usually assumed streamflow erosion of the bank materials, with consideration of seepage problems within the bank, rapid lowering of the stream water surfaces due to natural or man-controlled events, overbank drainage, bank materials, and other factors.

Laboratory tests are valuable in determining the relative effectiveness of various bank protection methods. Laboratory and field testing reinforced our knowledge of streambank erosion causes and controls. Many results were not totally unexpected but added to our information of streambank erosion mechanisms. Full-scale, demonstration project evaluation of many of the laboratory-tested techniques permits relative full-scale performance of nearly all the laboratory-tested techniques to be predicted with confidence from relative small-scale performance in the laboratories. Laboratory tests are also useful design tools that permit one to more accurately predict the length and extent to which bank protection should be carried upstream and downstream from the critical area. The potential cost savings from preconstruction laboratory investigations can be significant for large-scale problem areas.

Most of the demonstration projects covered only limited areas of the streams and any environmental effects were very local. In general, there were no adverse impacts anticipated, or the Corps provided for mitigation or did not use the site for a demonstration project. The Corps worked with concerned environmental interests, especially along the Missouri River, in obtaining information for possible extrapolation to long reaches of protection. No significant problems were encountered, and in some instances there were environmental benefits.

Some of the erosion protective systems investigated under this program are low-cost schemes that are designed to protect the bank against a limited number of critical events or to just mitigate the damages of a specific event. As a result, a higher level of maintenance will be required throughout the life of the structure. If they are permitted to degrade, the eroded-bank condition will redevelop. The maintenance and rehabilitation requirements cannot be predicted accurately at this time because of the limited period of observation.

Costs of protective schemes vary widely, depending upon the extent of the problem to be solved, the availability of locally available materials, and the size of the project. Some protective measures are very labor intensive, thus requiring hand placement of materials, whereas others are more suitable to large mechanized equipment. Generally the costs associated with small isolated problem areas far exceed the potential benefits; however, if several of these problem areas can be repaired concurrently, the projects, when grouped together, become more cost-effective. Familiarity with construction procedures, placement techniques, etc., all have a bearing on the ultimate cost of the project.

Bank protection materials in high-energy environments (turbulent flows, high velocity, waves) must be placed on appropriate granular or fabric filters to prevent the loss of bank material to the penetrating currents. In low-energy environments, however, it has been found that quarry-run riprap of sufficient size and thickness performs well.

A wide variety of both natural and man-made materials are currently available to control streambank erosion. These include concrete blocks in various configurations, rock riprap, rubber tires, vegetation schemes, concrete mattresses, soil-cement, etc. All of these materials have unique advantages and disadvantages depending upon the size of the area to be protected, the availability of the material, the cause of the bank instability, and the cost.

Rock is the most used material for protection against streambank erosion, although the methods of application and design vary widely. It will likely continue to be the first choice of bank protection materials where material of sufficient size is available and affordable, because of durability, and other advantages.

- A riprap blanket is flexible and is neither impaired nor weakened by slight movement of the bank resulting from settlement or other minor adjustments.
- Local damage or loss is easily repaired by the placement of more rock.
- Construction is not complicated and so special equipment or construction practice is not necessary.
- Riprap is usually durable and recoverable and may be stockpiled for future use.
- The cost-effectiveness of locally available riprap provides a viable alternative to many other types of bank protection.
- Riprap stability increases with increasing thickness as more material is available to move to damaged areas and more energy is dissipated before it reaches the filter and streambank.

The cost-effectiveness of riprap from a local source remains strongly competitive with other long-term protection types, and it is usually a very effective erosion protection device. In addition to riprap, the rock-dominated methods also afford some promise toward effectively controlling streambank erosion. For example, rock toes with suitable upslope vegetation function well in some situations. Similarly, the techniques of using rock hard points, jetties, and windrows provided adequate protection when properly designed, but some initial erosion should be anticipated before the units become effective. Gabions offer an effective bank protection technique where suitable riprap is not available.

In addition to rock or rock products, other techniques offer some promise under certain conditions to control streambank erosion. For example, soil-cement may be cost-competitive. Used-tire mattresses and bulkheads are an effective method of protection but have high labor costs for installation when accomplished under contract. Kellner jacks and permeable timber and wire fences with tiebacks are effective in low-energy environments.

In general, most techniques are not economically justified as costs still far exceed benefits using present criteria. One option may be to perform only minimal protection first, then repair as necessary, e.g., windrow revetment, low-elevation structures, intermittent bank-line revetment, or hard points. Also, low-grade materials may be satisfactory, e.g., chalk or poor quality rock. However, the most important conclusion is to provide effective protection at the toe of the bank.

Prediction of the when, where, and extent of streambank erosion and/or bank instability remains clouded. The forces contributing to streambank instability are generally known and understood; however, application of these principles to the real world are complicated by the many processes acting simultaneously throughout a given river reach. Streams displaying very active tendencies to erode their banks often seem to reverse themselves and display periods of relative stability. These processes will continue to make the prediction of erosion indeterminate, and most efforts to control the erosion will be based on after-the-fact information.

PART II: RECOMMENDATIONS

The following general recommendations of the Section 32 Program efforts have been collected or derived from the various parts of this Final Report to Congress. A large number of significant, but more specific or limited, recommendations are given in the individual parts of the report.

Monitoring of the demonstration projects should be continued in some manner where the site has not been adequately tested due to the demonstration projects having not experienced even moderate streamflows. Originally, an evaluation period of 3 to 5 years was considered to be adequate for the determination of the structural and functional soundness of a project. This period may not be long enough in some cases, and accordingly, arrangements should be made to continue monitoring and evaluation of these untested protection works in connection with the normal missions of the U. S. Army Corps of Engineers to gain valuable knowledge of the erosion process and protection techniques. In any event, observations of the demonstration projects will continue on an unscheduled basis in connection with the normal missions of the Corps of Engineers. Of the 50 revetment projects outside the Section 32 Program that were evaluated, only 9 projects have experienced significant damage requiring repair. Additionally, 10 others required maintenance and minor repairs due to soil settlement, vandalism, and flood flows. Of the 50 projects, 31 have not needed repairs or major maintenance.

Local interests will assume the maintenance and operation of the demonstration projects after they are no longer needed for testing and evaluation under the Section 32 Program. There were 68 demonstration projects constructed, and some of these projects did not experience an adequate testing period in terms of time or discharge. Of these untested projects, a few employ techniques or devices that may produce an unsound streambank condition if the techniques fail. At these sites, rehabilitation is generally being accomplished to assure a sound and functional project. However, a very few untested demonstration projects will remain in place without continued testing or future rehabilitation as long as there is no adverse impact on the community or the environment. All viable projects will have been transferred to the local sponsors by September 30, 1982.

Before any stabilization measures are planned by any interest, available data should be analyzed. This can be accomplished through a research of existing maps, surveys, topographic maps, aerial photographs, field investigations, discussions with local residents, and historical documentation of the area. This will assist designers to understand how the system has responded to changes in the past and how it may respond in the future.

The alignment of the structures is critical. During periods of high and low flows, the location of the major point of attack will usually vary. It is therefore necessary to define the limits for this point of attack to provide adequate bank protection for both high and low flows. The design should provide the highest degree of protection within the limits of the point of attack of high flows with a reduced level of protection upstream and downstream. The most common oversight in design is to extend bank protection too far upstream and not far enough downstream. Since bends migrate downvalley, the downstream end of protection is more critical; therefore care should be taken in establishing the lower limits of protection. The alignment of structures should provide a smooth transition from bendway to bendway. Both the high-water and low-water paths should be considered in the alignment design for development of an orderly transition between bendways, thereby preventing the structures from creating an obstruction to flow.

Where possible, natural levees along top bank should be left undisturbed by construction activity. Man-made replacements may not be adequate and may change the overbank drainage

patterns. Engineering techniques to control overbank drainage are necessary to prevent damage to the structure.

Basic research should be pursued on many aspects of stream behavior, especially those involving the interaction of erodible boundaries with the flowing water. The water flow and the soil boundaries are very extensive in both physical size and variety of their characteristics, with many interacting and continuously changing phenomena at every point of contact between the water and soil. Such research would lead to the level of understanding of stream behavior needed to accurately predict the behavior and optimum design of protective works.

Future investigations of streambank erosion control should include efforts to define stable bed slopes for streams. Most of the demonstration projects in the Section 32 Program addressed horizontal control of the bank alignment. A need exists for the optimum design of grade-control structures for wide ranges of soil and water flow conditions.

As a result of the demonstration program, many new or proposed erosion protection products or methods have appeared in the latter stages of the program such as: earth- or rock-filled grids, reinforced earth bulkheads, stabilized mattings for vegetation seeding, and many specific patented schemes using manufactured blocks in loose, matted, or interconnected configurations. Unfortunately, most of these have not been adequately tested and their relative merits are open to question. They should be evaluated in the laboratories and the better methods field-tested relative to their hydraulic and soil characteristics, as well as general performance, for comparison with other methods tested under the Section 32 Program. Also, some potentially low-cost methods are functioning satisfactorily in the field; but the limited duration of the demonstration program did not allow sufficient time for developing optimum designs that would be most effective.

It should be emphasized that this program was heavily experimental, and some failures were expected. Some structures were designed with marginal strength in an effort to determine the minimum amount of protection required to demonstrate that using inexpensive measures can, in some cases, be false economy. There is a difference between "expensive" work and "cost-effective" work. This is an extremely important point. "Cheap" solutions to significant erosion problems are not possible. However, an understanding of the stream's behavior allows the most effective use of funds, even though the amount of funds required may be significant or even prohibitive.

A systematic approach to the correction of streambank erosion problems offers the best long-term solution to a chronic national problem. Coordinated efforts, beginning with a proper evaluation of the causes of the erosion problem, are needed, accompanied by a thorough analysis of the problem throughout the drainage basin to provide long-term control. This analysis should consider an evaluation of environmental impacts of the proposed solution of both the riverine and adjacent land-use values, with the view of minimizing environmental losses.

PART III: INTRODUCTION

The United States contains nearly 3.5 million miles of rivers, creeks, and other such streams. On over one-half million (574,500) miles of bank line along these streams, damage is occurring from streambank surface erosion, sloughing, degradation of the bed, head-cutting, and or failure by collapse. (See Glossary in PART XVI of this report for definitions of these terms. The term "streambank erosion" as used in this report will usually include most of these types of damages.) The resulting total annual damages are a serious economic loss to both private and public interests located along these streambanks. The U. S. Congress recognized this problem and the potential benefits to be derived by controlling bank erosion, and legislation was enacted to develop guidelines for low-cost, effective bank protection for both public works and private citizens. The developmental program was conducted by the U. S. Army Corps of Engineers. The final report on the program consists of this Main Report and eight appendices.

BACKGROUND

The River and Harbor Act of 1968 (Title I of Public Law 90-483, Section 120) authorized and directed the Secretary of the Army, acting through the Chief of Engineers ". . . to make studies of the nature and scope of the damages which result from streambank erosion throughout the United States . . . ." The ensuing Report of the Chief of Engineers to the Secretary of the Army, *A Study of Streambank Erosion in the United States, August 1969*, indicated that total annual damages resulting from streambank erosion in the United States amounted to approximately $90 million (1969).* In comparison, the estimated total annual cost of conventional bank protection required to prevent the damages was estimated to be $420 million (1969), which emphasized the importance of developing low-cost methods to reduce the economic impact of streambank erosion problems. The 1969 report recommended a vigorous research and development effort, under existing agency authorities, to more fully understand the erosion processes and effects and to develop low-cost remedial measures.

AUTHORIZING LEGISLATION

In recognition of the serious economic losses occurring throughout the United States due to streambank erosion, the U. S. Congress passed the Streambank Erosion Control Evaluation and Demonstration Act of 1974, Section 32, Public Law 93-251 (as amended by Public Law 94-587, Section 155 and Section 161, October 1976). This legislation authorized a program that was established to include an updated analysis of the extent and seriousness of streambank erosion, research studies of soil stability and hydraulic processes to identify causes of erosion, an evaluation of existing bank protection techniques, and construction and monitoring of demonstration projects to evaluate the most promising bank protection methods and techniques. The program will be referred to in this report as the "Section 32 Program." A copy of the Section 32 Program legislation is given in Exhibit III-1.

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*July 1969 cost level; see PART IV of this report.

Exhibit III-1

SECTION 32 PROGRAM LEGISLATION

Public Law 93-251, Section 32, March 1974
As Amended* by Public Law 94-587, Section 155 and Section 161, October 1976

(a) This section may be cited as the "Streambank Erosion Control Evaluation and Demonstration Act of 1974."

(b) The Secretary of the Army, acting through the Chief of Engineers, is authorized and directed to establish and conduct for a period of five fiscal years a national streambank erosion prevention and control demonstration program. The program shall consist of (1) an evaluation of the extent of streambank erosion on navigable rivers and their tributaries; (2) development of new methods and techniques for bank protection, research on soil stability, and identification of the causes of erosion; (3) a report to the Congress on the results of such studies and the recommendations of the Secretary of the Army on means for the prevention and correction of streambank erosion; and (4) demonstration projects, including bank protection works.

(c) Demonstration projects authorized by this section shall be undertaken on streams selected to reflect a variety of geographical and environmental conditions, including streams with naturally occurring erosion problems and streams with erosion caused or increased by man-made structures or activities. At a minimum, demonstration projects shall be conducted at multiple sites on:

(1) the Ohio River;

(2) that reach of the Missouri River between Fort Randall Dam, South Dakota, and Sioux City, Iowa;

(3) that reach of the Missouri River in North Dakota at or below the Garrison Dam, and including areas on the right bank at river miles 1345; 1310; 1311; 1316.5; 1334.5; 1341; 1343.5; 1379.5; 1385; and on the left bank at river miles 1316.5; 1320.5; 1323; 1326.5; 1335.7; 1338.5; 1345.2; 1357.5; 1360; 1366.5; 1368; and 1374;

(4) the delta and hill areas of the Yazoo River Basin generally in accordance with the recommendations of the Chief of Engineers in his report dated September 23, 1972.

(5) the delta of the Eel River, California;

(6) the lower Yellowstone River from Intake, Montana, to the mouth of such river.

(d) Prior to construction of any projects under this section, non-Federal interests shall agree that they will provide without cost to the United States land, easements, and rights-of-way necessary for construction and subsequent operation of the projects; hold and save the United States free from damages due to construction, operation, and maintenance of the projects; and operate and maintain the projects upon completion.

(e) There is authorized to be appropriated for the ~~five fiscal year period ending June 30, 1978,~~ not to exceed ~~$25,000,000~~ $50,000,000 to carry out ~~subsections (b), (c), and (d) of~~ this section.

(f) The Secretary of the Army shall make an interim report to Congress on work undertaken pursuant to this section by September 30, 1978, and shall make a final report to the Congress no later than December 31, 1981.

The Public Works for Water and Power Development and Energy Research Appropriation Bill, Fiscal Year 1978, specified: ". . . . . work on the Fort Randall--Sioux City, Iowa reach of the Missouri River, including the Sunshine Bottom, Goat Island and Ionia Bend sites," at miles 868.5 right, 796.5 left and 761.0 right, respectively (see Section 32 paragraph (c)(2)).

The Public Works for Water and Power Development and Energy Research Appropriation Bill, Fiscal Year 1979, specified: " . . . . . work on the Fort Randall Dam to Sioux City reach of the Missouri River, including Cedar County Park and Elk Point." and " . . . . . unbudgeted funds for the following sites: White River at Jacksonport, Arkansas, $920,000; Missouri River, mile 755.5, $800,000; Missouri River, mile 795.5, $600,000; and Ohio River from Lawrence through Washington Counties, Ohio, $400,000."

The Energy and Water Development Appropriation Bill, Fiscal Year 1980, specified: " . . . . . areas on the Missouri River in Nebraska and South Dakota: Cedar County Park (Mile 798.5 of the Missouri River, Nebraska side), $318,000; Elk Point (Mile 755.5 of the Missouri River, South Dakota side), $833,000; White Swan Area (Mile 869 of the Missouri River below Fort Randall Dam), $627,000."

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* In the Section 32 Program legislation above, amendment additions are underlined and amendment deletions are lined through.

IMPLEMENTATION OF PROGRAM TASKS

A Steering Committee was formed to organize and coordinate the program, develop the scope of the work, review recommended demonstration project sites and types of protection to be investigated, establish monitoring guidelines, inspect demonstration projects, evaluate results, and prepare interim and final reports on the program. The Committee, composed of 17 representatives of various technical and functional disciplines from the Office, Chief of Engineers (OCE), each Continental United States Division of the Corps, and the Hydraulics and Geotechnical Laboratories of the U. S. Army Engineer Waterways Experiment Station (WES), met 14 times in 1976-1981 during the course of the Section 32 Program.

PROGRAM SCOPE

To accomplish the broad objectives of the authorizing legislation, the Steering Committee developed a program consisting of 10 work units:

1. Evaluation of extent of streambank erosion, nationwide.
2. Literature survey and evaluation of bank protection methods.
3. Hydraulic research on effectiveness of bank protection methods.
4. Research on soil stability and identification of causes of streambank erosion.
5. Ohio River demonstration projects.
6. Missouri River demonstration projects.
7. Yazoo River Basin demonstration projects.
8. Demonstration projects on other streams, nationwide.
9. Rehabilitation of demonstration projects.
10. Reports to Congress.

Brief descriptions of these work units are given in subsequent paragraphs.

Construction of demonstration projects specified by the Section 32 Program legislation encompassed a major portion of the effort (Work Units 5-8). These projects were undertaken on streams representing a variety of geographical and environmental conditions, including streams with naturally occurring erosion problems and streams with erosion caused or increased by man-made structures or activities. The 68 demonstration projects constructed under the legislation are listed in Exhibit III-2 and the locations are shown in Exhibit III-3.

EVALUATION OF EXTENT OF STREAMBANK EROSION, NATIONWIDE (WORK UNIT 1)

This evaluation updates the Corps of Engineers report, *A Study of Streambank Erosion in the United States, August 1969*. The findings in that report were reviewed and additional field investigations were made to update the extent of erosion. This work was completed in Fiscal Year 1977 and is summarized in PART IV of this report. The current total assessment of the extent of streambank erosion in the United States (March 1981 cost level) indicates:

Length of channels	3.5 million stream-miles
Length of erosion	575,000 bank-miles
Length of serious erosion	142,000 bank-miles
Total damages	$340,000,000 per year
Total damages from serious erosion	$250,000,000 per year
Estimated protection costs for serious erosion (by conventional methods)	$1,100,000,000 per year

These values confirm the need for developing lower cost techniques to provide the needed protection against erosion.

Exhibit III-2

COMPLETED DEMONSTRATION PROJECTS

	Project Length ft	No. of Protection Methods	Fiscal Year Completed	Total Cost* $1,000
OHIO RIVER				
1. Moundsville (Grave Creek), WV	1,850	6	1978	$ 199
2. Moundsville, WV	2,130	6	1977	160
3. Powhatan Point, OH	2,000	6	1979	176
4. St. Marys, WV	4,200	3	1981	397
5. Ravenswood, WV	1,390	4	1977	206
6. South Point, OH	1,300	4	1981	281
7. Portsmouth, OH	1,600	4	1977	251
8. Moscow, OH	1,300	3	1981	352
9. Mt Vernon, IN	750	4	1977	108
Subtotals	16,520			$2,130
MISSOURI RIVER				
In Nebraska				
10. Sunshine Bottom	8,600	4	1979	$ 695
11. Cedar County Park (2 parts)	10,300	3	1980	669
12. Brooky Bottom Road	18,500	3	1978	411
13. Mulberry Bend	7,400	3	1979	494
14. Ryan Bend	7,500	4	1979	254
15. Ionia Bend	10,900	5	1979	938
Subtotals	63,200			$3,461
In North Dakota				
16. Hancock	6,300	4	1981	$ 193
17. Knife Point I	3,700	3	1981	346
18. Knife Point II	3,100	3	1981	310
19. Sandstone Bluff I	9,300	1	1979	546
20. Sandstone Bluff II	10,500	3	1979	546
21. Coal Lake Coulee	3,100	5	1981	287
22. Lewis and Clark 4-H Camp	7,100	4	1979	261
23. Wildwood	3,100	4	1981	286
24. Sanger	1,500	1	1980	351
25. Pretty Point	3,000	5	1981	250
26. Price I	8,100	3	1981	509
27. Price II	2,700	2	1981	218
28. Horseshoe Butte	8,100	4	1981	392
29. Eagle Park	13,300	4	1980	639
30. Burnt Creek	8,500	5	1980	577
31. I-94 Highway	11,400	6	1980	1,159
32. Ft. Lincoln	5,700	5	1981	303
Subtotals	108,500			$7,171
In South Dakota				
33. White Swan	7,700	5	1981	426
34. Goat Island	12,400	4	1979	1,058
35. Vermillion Boat Club	21,600	3	1979	282
36. Vermillion River Chute	13,100	5	1979	780
37. Elk Point (2 parts)	17,200	5	1980	1,342
Subtotals	72,000			$3,888

	Project Length ft	No. of Protection Methods	Fiscal Year Completed	Total Cost* $1,000
YAZOO RIVER BASIN, MISSISSIPPI**				
Bank Stabilization				
38. Batupan Bogue, Grenada Co. (18 bendways)	16,000	12	1979	$ 2,971
39. Hunter Creek, Tallahatchie Co. (28 bends)	11,000	4	1979	585
40. Johnson Creek, Panola Co. (14 bends)	8,000	3	1979	243
41. N. Fk. Tillatoba Cr., Tallahatchie Co. (29 bends)	22,000	9	1977	1,160
42. Perry Creek, Grenada Co. (37 bends)	16,000	6	1978	704
43. S. Fk. Tillatoba Cr., Tallahatchie Co. (48 bends)	30,000	11	1979	1,782
Subtotals	103,000			$ 7,445
Grade-Control Structures				
44. Goodwin Creek, Panola Co. (14 sites)	51,000	2	1980	$ 2,645
45. Hotophia Creek, Panola Co. (5 sites)	33,000	2	1980	370
46. Johnson Creek, Panola Co. (3 sites)	42,000	2	1981	224
47. N. Fk. Tillatoba Cr., Tallahatchie Co. (2 sites)	100,000	2	1978	470
48. Perry Creek, Grenada Co. (2 sites)	25,000	2	1978	966
Subtotals	251,000			$ 4,675
YELLOWSTONE RIVER				
49. River Road, MT (near Sidney, MT)	600	1	1981	$ 123
50. Cheney Creek, ND (near Cartwright, ND)	2,400	1	1981	489
Subtotals	3,000			$ 612
EEL RIVER DELTA				
51. Eel River, Fernbridge, CA	2,500	4	1980	$ 373
52. Van Duzen River, Carlotta, CA	900	3	1979	144
Subtotals	3,400			$ 517
PROJECTS ON OTHER STREAMS, NATIONWIDE, NOT SPECIFIED IN AUTHORIZING LEGISLATION				
53. Allegheny River, Wattersonville, PA	2,200	6	1980	$ 242
54. Connecticut River, Haverhill, NH	2,500	7	1979	439
55. Connecticut River, Northfield, MA	2,000	5	1981	532
56. Delaware River, Paulsboro, NJ	2,200	6	1980	256
57. Green River, Kent, WA	2,000	3	1981	462
58. Kansas River, Eudora, KS	2,300	4	1979	180
59. Kanawha River, South Charleston, WV	1,600	4	1980	545
60. Iowa River, Wapello, IA	2,200	3	1978	223
61. Little Miami River, Milford, OH	1,000	3	1978	553
62. Lower Chippewa River, Eau Claire, WI (5 sites)	9,900	19	1981	423
63. Pearl River, Monticello, MS (3 sites)	1,000	3	1981	353
64. Rio Chama, Abiquiu, NM	886	3	1981	160
65. Roanoke River, Leesville, VA (2 sites)	2,000	3	1981	34[illegible]
66. Sacramento River, Ordbend, CA	1,500	1	1981	591
67. White River, Jacksonport, AR	3,840	13	1980	474
68. White River, Des Arc, AR	1,000	3	1980	710
Subtotals	38,126			$ 6,485
GRAND TOTALS	678,746			$36,384
	(124.8 miles)			

NOTE: Projects 1-52 were constructed in response to Section 32 Program legislation; projects 53-68 were selected by steering committee. See locations on Exhibit III-3

* Includes construction, engineering and design, supervision and administration costs.

** This list of 68 demonstration projects is based on 11 geographically/structurally identified Yazoo River Basin projects which represent 20 contractual projects under the Section 32 Program for a total of 77 projects used in some previous reporting) plus 3 additional projects from the Yazoo Basin "pilot study" that preceded the Section 32 Program

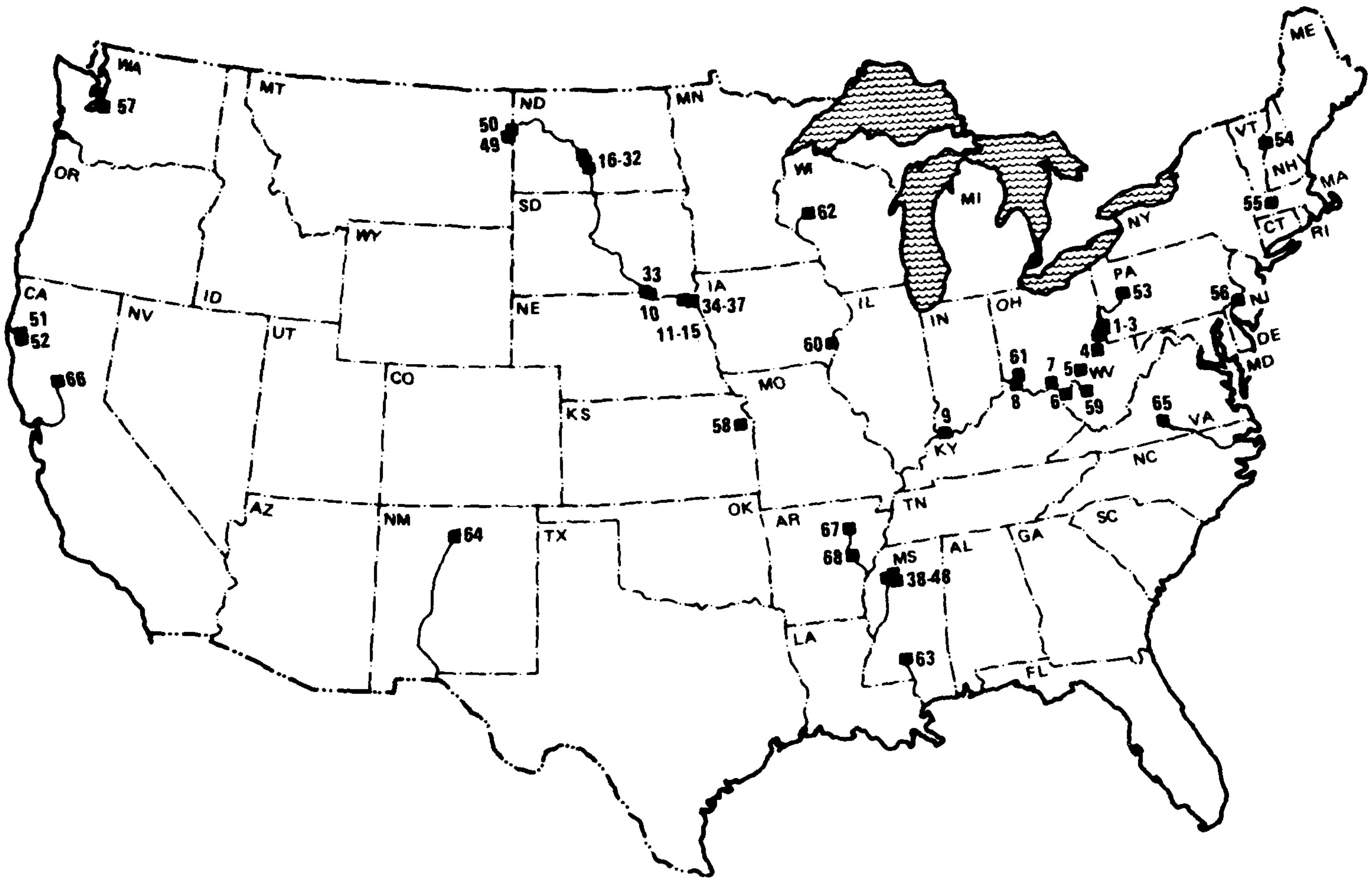


Exhibit III-3. Locations of demonstration projects

LITERATURE SURVEY AND EVALUATION OF BANK PROTECTION METHODS (WORK UNIT 2)

WES conducted a literature survey of existing streambank protection methods, on which the first of two volumes was published and widely distributed in 1977 and both volumes are combined in Appendix A of this report. WES and the Corps Districts observed and evaluated the effectiveness of bank protection methods at 50 existing Corps and other agency projects constructed prior to or separate from the Section 32 Program, as well as at the 68 Section 32 Program demonstration projects constructed under the authorizing legislation. Additional details of this work are given in PARTS V and XIII and Appendices A and H of this report.

HYDRAULIC RESEARCH ON EFFECTIVENESS OF BANK PROTECTION METHODS (WORK UNIT 3)

Hydraulic research was conducted at WES and the Missouri River Division Mead Hydraulic Laboratories, using scale models to evaluate existing and new methods and techniques of protecting streambanks subject to attack by streamflow, wave action, fluctuating water levels, and passing vessels. Scale model demonstration tests were made for comparative evaluation of varying amounts of conventional protection and for many alternates. The hydraulic research efforts of the Section 32 Program were coordinated with those conducted by the Coastal Engineering Research Center for the Section 54 Program, Shoreline Erosion Control Demonstration Act of 1974 (Public Law 93-251). Additional details on the hydraulic research efforts are given in PART VI and Appendix B of this report.

RESEARCH ON SOIL STABILITY AND IDENTIFICATION OF CAUSES OF STREAMBANK EROSION (WORK UNIT 4)

Selected aspects of streambank erosion and control were investigated at the WES Geotechnical Laboratory, supplemented by contract studies at the University of California, Davis, and further supported by academic and technical advisors. The laboratory research addressed the influence of soil properties on erodibility and bank stability; procedures were suggested for including erosional effects in bank stability analyses. Materials and construction methods previously developed in surface stabilization research were adapted to bank protection using laboratory modeling techniques and experimental field installations. The research and significant findings are described in PART VI and Appendix C. Geomorphic and waterborne geophysical onsite field studies, related to causes and mechanisms in the streambank erosion processes, are discussed in PART VII and Appendix C.

DEMONSTRATION PROJECTS OF STREAMBANK PROTECTION (WORK UNITS 5, 6, 7, AND 8)

Corps of Engineers District and Division offices planned, designed, constructed, and monitored demonstration projects at 68 selected locations on numerous streams throughout the United States. The objective was to demonstrate economical and effective methods of streambank protection that will control bank erosion and thus minimize the permanent loss of adjacent property. Potentially low-cost methods and materials were tested at representative streambank sites to evaluate and demonstrate their suitability for wide-scale use. All proposed construction was first coordinated with local authorities and private interests, and contractual agreements were reached before construction began. Local sponsors were required for each

demonstration project, and these agreements included responsibilities for operation and maintenance of the projects after the results of the demonstration program have been obtained. Detailed reports on these projects were prepared to formally record site, construction, and performance information. The reports on demonstration projects in Work Units 5, 6, 7, and 8 are included in Appendices D, E, F, and G, respectively. Summaries of these project reports are given in PARTS VIII to XIV of this Final Report.

Ohio River Demonstration Projects (Work Unit 5)

The Corps Districts in the Ohio River Division investigated numerous sites on the Ohio River and tributaries where active streambank erosion was occurring. The two Ohio River tributary demonstration projects at Milford, Ohio, on the Little Miami River and at South Charleston, West Virginia, on the Kanawha River are reported in the Demonstration Projects on Other Streams, Nationwide (Work Unit 8) along with the project at Wattersonville, Pennsylvania, on the Allegheny River.

Missouri River Demonstration Projects (Work Unit 6)

A total of 28 demonstration projects were constructed along three reaches of the Upper Missouri River. Seventeen of these projects are located downstream from Garrison Dam in North Dakota, two downstream from Fort Randall Dam in Nebraska and South Dakota, and nine downstream from Gavins Point Dam along the Nebraska and South Dakota border. All of the 17 projects in North Dakota were at sites specifically authorized by Congress, whereas the remaining reaches included sites selected by the Steering Committee. Priority was placed on providing protection at locations where erosion rates were highest. Funding limitations resulted in some of the projects being scaled down from the original proposals.

Yazoo River Basin Demonstration Projects (Work Unit 7)

The Section 32 Program legislation specified conducting demonstration projects in "the delta and hill areas of the Yazoo River Basin generally in accordance with the recommendations of the Chief of Engineers in his report dated September 23, 1972." Demonstration projects were constructed and monitored at numerous sites in 11 general locations in the Yazoo River Basin. In addition to these projects, cooperative efforts with other agencies were arranged to address special areas of interest regarding streambank erosion in the Yazoo River Basin. This work included studies of sediment transport, tests of vegetal covers for possible use in this region, and an inventory of bank stabilization methods used by the U. S. Soil Conservation Service.

Demonstration Projects on Other Streams, Nationwide (Work Unit 8)

A variety of streambank protection methods and materials were evaluated at other selected sites nationwide to demonstrate their capability to perform under a broad range of geographical and environmental conditions. Work Unit 8 was composed primarily of demonstration projects that were not specified by the original Section 32 Program legislation. The Eel and Yellowstone Rivers sites are exceptions that were added as an amendment in 1976 to Section 32 of Public Law 93-251 and were included under this work unit for reporting purposes. The work unit consisted of constructing and monitoring 20 projects on 16 different streams throughout the United States. Included were sites where streambank loss is the result of flow velocity, wave action, ice scour, water-surface fluctuation, and or bank instability.

REHABILITATION OF DEMONSTRATION PROJECTS (WORK UNIT 9)

The Corps of Engineers field offices constructed demonstration projects throughout the United States. At each demonstration project, various streambank protection materials and techniques were used to demonstrate potential low-cost erosion control methods. Accordingly, some of the minimal types of bank protection methods being tested were damaged during the monitoring period. The damaged projects were rehabilitated, as necessary and as availability of funds permitted, to provide adequate bank protection before the demonstration projects were transferred to the local sponsors. Originally, an evaluation period of five years after completion of initial construction was desired for the determination of the structural and functional soundness of the demonstration project. However, practically no projects will have been monitored for the five-year period when the Section 32 Program ends. Some additional monitoring efforts will be accomplished in coordination with the normal Corps missions. Longevity alone does not classify an innovative streambank erosion control method as a proven low-cost technique because in some cases substantial streamflows have not been experienced at the demonstration project.

REPORTS TO CONGRESS (WORK UNIT 10)

The authorizing legislation specified that the interim and final reports to Congress on the Section 32 Program would be made by 30 September 1978 and 31 December 1981, respectively. The widely distributed Interim Report consisted of a brief main report and appendices that summarized the status of activities and funding of the program through FY 1978 and presented proposed activities and funding for the remainder of the program. It also included brief descriptions of the many demonstration projects completed or under construction at that time.

SCOPE OF FINAL REPORT

This Final Report to Congress on the Section 32 Program consists of a main report summarizing the activities, findings, and pertinent recommendations of the program and the general results to date. Details are given on the extent of streambank erosion, related work by others on erosion control, hydraulic and geotechnical laboratory investigations, causes and mechanisms of streambank erosion and failure, findings from 68 demonstration projects and 50 other projects constructed prior to or separate from the Section 32 Program, and procedures for preventing or correcting streambank erosion. Eight appendices contain detailed results of the various investigations and demonstrations. An information pamphlet is being prepared to assist local interests and individuals in self-help protection work for streambank erosion control. New technical knowledge resulting from the program is being incorporated into pertinent Corps of Engineers design guidance.

PROGRAM SCHEDULE AND FUNDING

The original Act of 1974 (see Exhibit III-1) authorized appropriations not to exceed $25,000,000 for the five-fiscal-year period ending 30 June 1978 to carry out the program. The 1976 amendment to the Act increased the authorized funding to a maximum of $50,000,000 and specified a final reporting date of 31 December 1981. Actual funding through FY 1981 and anticipated FY 1982 funding for the Section 32 Program are shown in Exhibit III-4.

Exhibit III-4

SECTION 32 PROGRAM FUNDING SCHEDULE

No.	Work Unit Title	FY Funds in $1,000 75	76	76T	77	78	79	80	81	82	Totals
1	Evaluation of Extent of Streambank Erosion, Nationwide	0	97	146	320	-114*	0	0	0	0	449
2	Literature Survey and Evaluation of Bank Protection Methods	0	50	75	125	105	150	90	140	0	735
3	Hydraulic Research on Effectiveness of Bank Protection Methods	0	100	150	400	370	275	275	100	0	1,670
4	Research on Soil Stability and Identification of Causes of Streambank Erosion	0	50	75	375	370	275	235	100	0	1,480
5	Ohio River Demonstration Projects**	0	500	650	555	-17*	505	354	-15*	0	2,532
6	Missouri River Demonstration Projects	50	500	750	1,000	2,500	4,575	4,595	2,050	107	16,127
7	Yazoo River Basin Demonstration Projects†	200	1,849	1,270	3,000	2,700	2,280	2,500	309	500	14,608
8	Demonstration Projects on Other Streams, Nationwide††	0	200	400	425	2,298	3,595	1,780	320	0	9,018
9	Rehabilitation of Demonstration Projects	0	0	0	0	0	0	134	483	668	1,285
10	Reports to Congress	0	0	0	0	35	100	100	270	225	730
	Totals	250	3,346	3,516	6,200	8,247	11,755	10,063	3,757	1,500	48,634

* Funds transferred to other Work Units.
** Includes Milford, OH (Little Miami River), and South Charleston, WV (Kanawha River).
† Mississippi River and Tributaries funds are used for Yazoo River Basin Demonstration Projects. All other funds are Construction, General.
†† Includes Yellowstone and Eel Rivers.

PART IV: EXTENT OF STREAMBANK EROSION IN THE UNITED STATES

Evaluation of the extent of streambank erosion and damages on navigable rivers and their tributaries was conducted in a manner similar to that of the 1969 study under Public Law 90-483. Data on natural and man-induced streambank erosion were collected or estimated in 1977 for all rivers, streams, and man-made channels with contributing drainage areas generally larger than 1 square mile. These data were compiled by water resources regions (Exhibits IV-1 and 2). The banks of bays, seacoasts, lakes, and reservoirs were excluded. More extensive field investigations, reconnaissance surveys, and use of sampling and extrapolation techniques were employed in the 1977 study than in the 1969 study. Other agencies that participated in the 1969 study, particularly the Soil Conservation Service, also contributed to the new evaluation of extent of streambank erosion.

NATURE OF DAMAGES

As used in both the 1969 and 1977 studies, the term "damages" refers to a direct or indirect loss of income (or increase in costs), or reduction in environmental quality as a result of streambank erosion. Three categories were recognized: land loss, sediment, and others.

Land Loss

The most apparent damage from bank erosion results from the loss of land. Precisely used, land loss would only be applied to those cases where the stream morphologic process results in channel enlargement. Usually, however, the term is used to describe the exchange of land that occurs (a) when land is lost at the concave bank by erosion and is gained at the convex bank by deposition; or (b) when the stream cuts a new channel and abandons the old one. In most cases such an exchange creates a net economic loss since the "new" land is of uncompacted, generally coarse soil and is lower in elevation. Rarely is it immediately as valuable or productive as the land that was eroded. In addition, costly resurvey and litigation may be necessary to settle disputes that arise if the stream is being used as real estate property boundaries. Also included in the land loss category of damage is the underutilization of land due to the threat of bank erosion. The potential for substantial economic damages due to land loss is often great in highly developed urban areas.

Sediment

Although streambank material erosion contributes to the total sediment load of the Nation's streams, it is not nearly as large a contributor as sheet and gully erosion. Suspended sediment from any source can increase water treatment costs and adversely affect the operating life of machinery, shellfish quality, recreational use, and aesthetic values. Extensive dredging is necessary to remove accumulated sediment in order to maintain adequate harbor and waterway depths. Deposited sediment reduces the value of fish and shellfish habitat and increases the required amount of total storage (and thereby the cost) of reservoirs. While soil particles are carried in suspension or moved along as bed load, chemical compounds previously existing in the bank material may become part of the stream's dissolved solids. Some of the compounds contain nutrient elements such as phosphorous and nitrogen that stimulate the rapid growth of obnoxious plants and organisms, which upon decay, decrease water quality. In contrast to other types of streambank erosion damages, sediment damages usually occur far from the site of the erosion.

Exhibit IV-1

NATIONAL ASSESSMENT OF STREAMBANK EROSION

Region	Region Totals: Length of Channels Stream-Miles	Region Totals: Length of Erosion Bank-Miles	Extent of Erosion Meriting Further Examination: Length of Erosion Bank-Miles	Extent of Erosion Meriting Further Examination: Average Annual Damages $1,000*	Extent of Erosion Meriting Further Examination: Average Annual Treatment Cost $1,000*
Alaska	568,000	58,000	-**	1,000	900
Arkansas-White-Red	218,300	56,500	22,800	79,000	278,600
California	133,000	50,600	8,100	47,500	47,100
Pacific Northwest	345,400	33,600	21,200	19,900	51,500
Colorado (Upper and Lower)	295,900	24,600	3,900	4,100	9,600
Great Basin	152,700	5,000	300	400	500
Great Lakes	66,100	9,100	4,500	2,300	21,700
Hawaii	2,600	0	0	0	0
Lower Mississippi	88,400	15,500	12,700	32,900	158,300
Middle Atlantic	95,700	28,500	8,000	9,200	41,300
Missouri Basin	538,200	52,800	11,800	14,200	66,400
New England	48,200	1,900	400	1,300	3,500
Ohio	147,200	27,300	6,800	4,800	33,400
Rio Grande	101,800	54,800	7,100	8,900	153,200
Souris-Red-Rainy	67,200	1,200	100	1,000	1,000
South Atlantic Gulf	213,300	37,900	22,300	10,000	33,900
Tennessee	32,800	4,100	1,700	800	1,500
Texas Gulf	149,500	98,300	4,300	6,600	179,800
Upper Mississippi	198,200	14,800	6,100	4,900	21,100
United States Total	3,462,500	574,500	142,100	$248,800	$1,103,300

* March 1981 cost level.
** Less than 50 bank-miles.

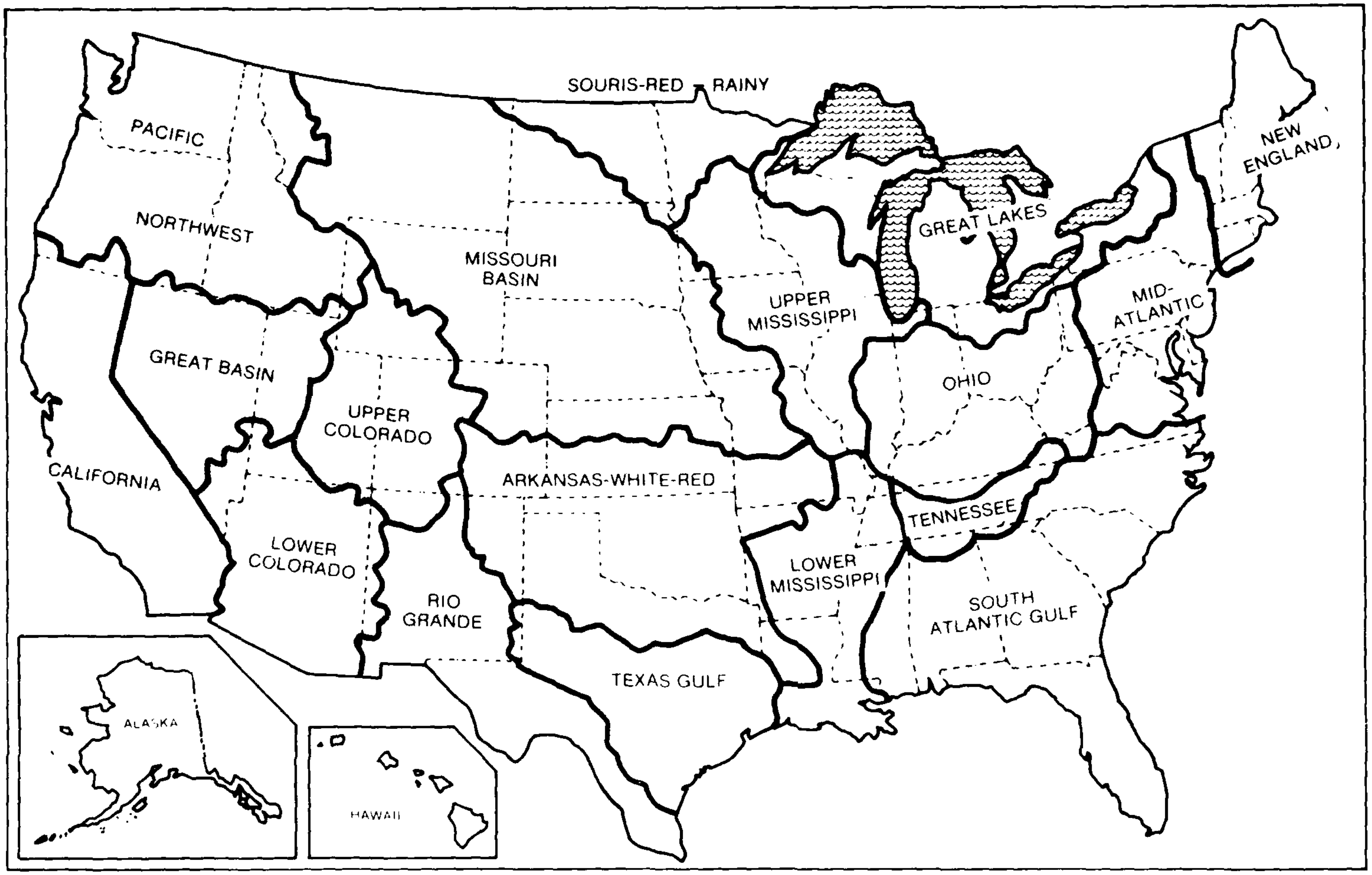


Exhibit IV-2. Water resources regions

Other Damages

For various reasons, many public and private facilities are located on streambanks. Damages occur to these facilities when the bank erodes sufficiently to preclude safe operation. Where the failure of some structural feature such as a floodwall, bridge, or water treatment plant would endanger life and health, virtually no erosion can be tolerated. Another type of damage occurs when undermined trees and brush that fall into the channel become unsightly debris and submerged logs that may clog channels, raise flood heights, and damage commercial and recreational vessels unless removed. With few exceptions, the eroded banks are themselves unsightly and contribute to a reduction in environmental quality.

EVALUATION METHOD

The method of evaluating the extent of streambank erosion in the Nation for both the 1969 and 1977 studies was to determine for each of the 19 major water resources basins: (a) total length of channels in stream-miles, (b) total length of erosion in bank-miles, (c) length of erosion in bank-miles meriting further examination, (d) average annual damages of the erosion meriting further examination, and (e) average annual treatment cost for preventing that erosion meriting further examination. Average annual damages and treatment costs were determined by using the same average unit costs per bank-mile as were used in the 1969 report, adjusted by the Engineering News Record construction cost index* to account for the price increases from July 1969 to January 1978 for the Interim Report to Congress, and to March 1981 for this report. National values were obtained by adding regional values, as shown in Exhibit IV-1, which is essentially an update of Table 1 in the 1969 study report. This evaluation of the extent of streambank erosion, including damages and treatment costs, is based on a current 1981 discount rate of 7-3/8 percent and a project life of 50 years.

EVALUATION LIMITATIONS

The 1977 evaluation confirms the previous 1969 finding that only a small amount of reliable data is available on the extent and nature of streambank erosion. Of the approximately 3,463,000 stream-miles in the United States, only about 20,000 stream-miles have been subjected to prior detailed studies. Estimated data had to be developed for the remaining 99-plus percent of the country's streams, using techniques considered appropriate for the streams in question. These data help to fill an important water resources information gap and provide an improved assessment of the extent of streambank erosion in the United States. However, as in the case of the 1969 study, the data contained herein are generally not of sufficient accuracy and detail to serve other purposes, such as project justification and authorization.

EXTENT OF STREAMBANK EROSION

The 1977 evaluation reveals that out of an estimated 3-1/2 million miles of streams (7 million bank-miles), approximately 8 percent or about 575,000 bank-miles is experiencing some erosion. Available data indicate that the total damages for all degrees of bank erosion are over $340 million annually (March 1981 costs). Since much of the total erosion causes only nominal damages, the Section 32 Program concentrated on severe streambank erosion which

* The Engineering News Record (ENR) construction cost index was 1283 in July 1969, 2672 in January 1978, and 3384 in March 1981 (ENR, 19 March 1981, page 133).

merits evaluation of practicable action to prevent or reduce the damages. Severe erosion, reported on only 2 percent (142,000 bank-miles) of the 7 million bank-miles in the Nation, results in estimated total damages of about $250 million annually (March 1981 costs). Subsequent detailed observations on specific streams during other activities under the Section 32 Program suggest that this estimated length of severe erosion could be low by a factor of 10 in some basins if all sizes of streams and drainage gullies are included. The cost of detailed studies for all 142,000 bank-miles of severe erosion meriting further examination to appraise the need for and feasibility of reducing the damages is estimated to be about $420 million (March 1981 costs). This figure assumes that every mile of erosion would be investigated to the same degree. Relatively early in such studies a substantial number of miles would show evidence of not satisfying economic justification criteria and would be excluded from further consideration, thereby lowering the total study cost considerably.

TREATMENT COSTS

The estimated annual cost to prevent the more serious streambank erosion meriting further examination is over $1100 million (March 1981 costs), based on protection methods presently in use. The national total, equivalent average annual cost of $7800 per mile, varies from $900 to $41,800 per mile among the regions listed in Exhibit IV-1 and would vary even more among the full range of individual stream and project conditions (channel size, flows, soils, etc.). The banks of small, fast-flowing streams may be as costly per mile to protect as large, slow-flowing streams. These studies indicate that for most stream reaches the cost of preventing streambank erosion would greatly exceed the damages being sustained. There are many specific locations, however, where prevention of damage merits the cost of protection. Also, methods of erosion control evaluated by research and demonstration projects under the Section 32 Program indicate potentially cost-effective alternatives. The overall average annual cost of Section 32 Program demonstration projects (based on Exhibit III-2) was $22,132 per mile, but these projects had higher design costs, smaller quantities, and higher contract prices than would be expected for normal projects.

SUMMARY AND CONCLUSIONS

Evaluation of the extent of streambank erosion under the Section 32 Program shows that of a total of nearly 3-1/2 million stream-miles in the Nation, 575,000 bank-miles have some degree of erosion, while 142,000 bank-miles have severe erosion meriting further examination. Although some regional data differed significantly, particularly those for the bank-miles meriting further examination, national totals differ only by small amounts from corresponding 1969 amounts (550,000 and 148,000 bank-miles of erosion, respectively). Of the 19 water resources regions shown in Exhibit IV-2, only Hawaii appears to be unaffected. The 1981 estimated average annual damages of about $250 million and average annual treatment costs of over $1100 million for erosion meriting further examination are over 2-1/2 times the corresponding values of about $90 million and $420 million for the 1969 study. These increases correspond closely to the 164 percent increase in the construction cost index between July 1969 and March 1981. The current evaluation confirms the 1969 study that streambank erosion is widespread. The estimated annual cost of treatment for the prevention of erosion damages indicates that most areas suffering damages cannot be economically treated, based on benefit/cost criteria. Stream reaches meriting treatment, for the most part, will be widely scattered and located in substantially populated and developed areas where land costs are high or near bridges or other structures. Some of the protection methods developed under the Section 32 Program will lower the treatment costs for some types of problems and increase the number of areas for which bank protection can be justified.

PART V: RELATED WORK BY OTHERS ON STREAMBANK EROSION CONTROL

Efforts to prevent and control streambank erosion date from antiquity (probably as early as 4000 B.C. in China or 5000 B.C. in Mesopotamia). Through the years countless individuals as well as local, regional, and national organizations and agencies have expended substantial resources on this problem with varying degrees of success and failure. In order to use as much of this past experience as possible in the Section 32 Program, an extensive literature survey was conducted as part of the program. Contacts were made with many other agencies and programs to find additional information and avoid possible duplication of previous efforts. No attempt was made to consolidate all of this information into a single comprehensive treatise; instead, as many of the currently pertinent concepts as possible were incorporated into the Section 32 Program.

LITERATURE SURVEY AND PRELIMINARY EVALUATION OF BANK PROTECTION METHODS

During 1975 and 1976 extensive sources of literature pertaining to the causes of bank erosion and methods of protection used were examined. A large number of streambank protection methods were identified and the results published in 1977 were widely distributed. That literature survey of about 1900 citations, included in Appendix A of this Final Report, also has information relevant to the mechanics of streambank erosion, preliminary assessment of existing methods for bank stabilization, a listing of some new methods of protection, conclusions relative to the current state of the art, recommendations of needed research and criteria, a listing of commercial concerns that market streambank protection products, a glossary of streambank protection terminology, and selected bibliographies on streambank protection. During the course of the Section 32 Program through 1977-1981, many more informative references, old and new, were found. These number about 1500 and are also provided in Appendix A.

WORK BY OTHER AGENCIES AND PROGRAMS

Coordination of the Section 32 Program with other agencies and programs was accomplished through various formal and informal means, varying from the Federal Interagency Research Coordination Conference to personal contacts by members of the Steering Committee. The recent and current work by others was generally a part of specific river basin studies or particular channel or streambank problems within an agency. A number of such programs and projects are:

Arkansas River, Oklahoma
Feasibility Report for Bank and Channel Stabilization
U. S. Army Engineer District, Tulsa, Oklahoma; report dated December 1977

> A study to determine the feasibility of providing bank and channel stabilization improvements on the Arkansas River between Keystone Lake and Webbers Falls Lock and Dam. (U. S. Senate Committee on Public Works resolution of 29 July 1965.)

Connecticut River, Massachusetts, New Hampshire, and Vermont
Streambank Erosion Study
U. S. Army Engineer Division, New England; report dated November 1979

A study to assess the causes of streambank erosion and possible corrective measures from Turners Falls Dam, Massachusetts, to the headwaters of Wilder Dam in New Hampshire and Vermont. (U. S. House of Representatives Committee on Public Works resolution of 11 April 1974.)

Des Moines River Bank Erosion Study, Iowa and Missouri
U. S. Army Engineer District, Rock Island, Illinois; Stage II Final Feasibility Report, August 1979

A study to determine causes of streambank erosion and feasibility of providing erosion control works along the Des Moines River below Red Rock Dam. (U. S. Senate Committee on Public Works resolution of 24 January 1974.)

Verification of Empirical Method for Determining Riverbank Stability (Mississippi River)
U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi; continuing study since 1952

This study is a test of empirical criteria for stability of banks with regard to flow slides (liquefaction-type failures) rather than complete bank stability analyses. Investigations of nearly 200 flow failures have proven the criteria to be reliable. (Sponsored by Mississippi River Commission, Vicksburg, Mississippi.)

A Study of the Upper Mississippi River
Great River Environmental Action Team (GREAT), St. Paul, Minnesota; GREAT I report dated September 1980

An interagency study on the development of a river system management plan for the Mississippi River incorporating total river resource requirements; GREAT I - Minneapolis, Minnesota, to Guttenberg, Iowa; GREAT II -Gutten berg, Iowa, to Saverton, Missouri; and GREAT III - Saverton, Missouri, to the mouth of the Ohio River. (Section 117 of Water Resources Development Act of 1976, Public Law 94-587.)

Missouri River, South Dakota, Nebraska, North Dakota, Montana
Review Report for Water Resources Development
U. S. Army Engineer Division, Missouri River; report dated August 1977

A consolidated study of a wide range of water resources problems and opportunities all having in common some link with the Missouri River. (Fifteen Congressional resolutions and five items in River and Harbor or Flood Control Acts, 1938 to 1970.)

Ohio River Bank Erosion Study
Ohio River Division Field Study Group
U. S. Army Engineer Division, Ohio River; report dated July 1977

A study to develop and analyze technical and historical data in order to arrive at professional and documented conclusions regarding whether the raising of the pools behind the Cannelton and Meldahl navigation structures was a cause of bank slumping or erosion at 22 specific sites. (Ohio River Division Engineer letter of 11 April 1977, "Ohio River Division Study Group for Bank Erosion Claim Litigation.")

Sacramento River and Tributaries Bank Protection and Erosion Control Investigations
U. S. Army Engineer District, Sacramento, California; report in preparation

A study of new and existing field data between Chico Landing and Ord Ferry to determine if bank protection reduces the sediment load in the stream and to develop guidelines for improved bank protection. (U. S. House of Representatives Committee on Public Works resolution of 2 December 1970.)

Willamette River Basin Streambank Stabilization by Natural Means
U. S. Army Engineer District, Portland, Oregon; report dated June 1976

An investigation to develop information on "natural means of streambank stabilization, including physical shaping of the bank, vegetative management, and land management adjacent to the streambank. (Conducted by Water Resources Institute, Oregon State University, Corvallis, Oregon.)

Yellowstone River Erosion Control Demonstration Program, Intake, Montana, to Mouth
U. S. Army Engineer District, Omaha, Nebraska; Background Study Report, December 1978

A program to develop methods of preventing undesirable streambank erosion while maintaining or enhancing wildlife and aquatic habitat (Conducted by Engineering Consultants, Inc., Denver, Colorado.)

U. S. Department of Agriculture, Soil Conservation Service (SCS) and Science and Education Administration (SEA)

A survey was made of SCS offices throughout the United States regarding the conventional and new types of protection methods used or recommended by that agency and to identify any SCS projects that might be monitored under the Section 32 Program. They evaluated the existing work on the Winooski River, Vermont, which they had originally constructed (see Appendix H). The SEA Sedimentation Laboratory at Oxford, Mississippi, participated in the Yazoo River Basin Demonstration Projects.

Countermeasures for Hydraulic Problems at Bridges
U. S. Geological Survey, Menlo Park, California; report dated September 1978

Study to develop measures for use in design, construction, and maintenance that will reduce bridge losses attributable to scour and bank erosion. Guidelines developed from literature survey and case histories of 224 bridge sites. (Sponsored by Federal Highway Administration, U. S. Department of Transportation.)

National Crushed Stone Association, Washington, D. C.
Erosion Control Task Group

Discussions between crushed stone producers and Corps of Engineers personnel have been initiated to better relate efficient stone production practices to streambank protection requirements.

National Waterways Study
U. S. Army Engineer Institute for Water Resources; reports in preparation

A study to review the existing United States waterways system and its capability for meeting national needs, including defense and emergency requirements, and to appraise additional improvements to meet the future needs. (Section 158 of Water Resources Development Act of 1976, Public Law 94-587.)

An Evaluation of River Restoration Techniques in Northwest Ohio
Institute of Environmental Sciences, Miami University, Ohio; report in preparation

A documentation and evaluation of correcting stream channel alignment and controlling bank caving by selective cutting and or moving of growing and or fallen trees along a stream. (Sponsored by U. S. Army Engineer Institute for Water Resources.)

Environmental and Water Quality Operational Studies
U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi; continuing since 1978

A program to provide new or improved technology for planning, design, construction, and operation of Corps of Engineers Civil Works projects to meet environmental quality objectives in a manner compatible with authorized project purposes. The Waterway Field Studies consist of long-term, comprehensive studies involving channel alignment, bank stabilization, or navigation channelization. (U. S. Army Engineer Civil Works Research and Development Program.)

Shoreline Erosion Control Demonstration Program
U. S. Army Engineers; final report in press

A five-year program to develop, demonstrate, and disseminate information about low-cost means to prevent and control shoreline erosion. Demonstration projects were constructed at 16 sites. (Shoreline Erosion Control Demonstration Act of 1974, Section 54 of Public Law 93-251.)

Section 55 Program (Public Law 93-251)
U. S. Army Engineers; continuing

"The Secretary of the Army, acting through the Chief of Engineers, is authorized to provide technical and engineering assistance to non-Federal public interests in developing structural and nonstructural methods of preventing damages attributable to shore and streambank erosion."

U. S. Army Engineer Committee on Channel Stabilization

The objectives of the Committee, with respect to channel stabilization are: (a) to review and evaluate pertinent information and disseminate the results thereof; (b) to determine the need for and recommend areas of productive research and to accomplish advisory technical review of research when requested; (c) to determine basic principles and design guidance; and (d) to provide, at the request of field offices, advice on design and operational problems. It is anticipated that this Committee will continue the review and evaluation of concepts intitiated, but not completed, in the Section 32 Program.

LMVD MRC Potamology Program
U. S. Army Engineer Division, Lower Mississippi Valley and Mississippi River Commission, Vicksburg, Mississippi; continuing since 1932

A program to provide new or improved technology for design and construction of channel improvement works to stabilize the Mississippi River so that it maintains dependable flood profiles and to provide a dependable and efficient low-water navigation channel in accordance with authorized project dimensions. The potamology studies consist of long-term, comprehensive studies involving hydrology, hydraulics, sedimentation, geomorphology, and channel morphology.

Effects of Bank Stabilization on the Physical and Chemical Characteristics of Streams and Small Rivers
University of Missouri - Kansas City and Rolla; Synthesis Report and Annotated Bibliography, July 1980

A synthesis of available literature (109 references) relating the effects of bank stabilization to the physical and chemical characteristics of streams; the bibliography has 213 references. (Sponsored by Fish and Wildlife Service, U. S. Department of the Interior.)

Streambank Erosion in Oregon
State Soil and Water Conservation Commission; Report to the 57th Legislative Assembly, 1973

A statewide study of streambank erosion within the 57 Soil and Water Conservation Districts in Oregon.

Evaluation of Quality and Performance of Stone as Riprap or Armor
U. S. Army Engineers; Rock Research Program of the Civil Works Investigation Study on Materials
U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi; Technical Report GL-81-8, September 1981.

A summary of Corps of Engineers experiences within the past 10 years, defining and describing problems with riprap and armor slope protection and identifying aspects needing further study

PART VI: LABORATORY INVESTIGATIONS

Laboratory investigations of some major hydraulic and geotechnical aspects of streambank erosion and its control were conducted to supplement the full-scale Section 32 Program demonstration projects. Using small-scale experiments in the laboratory, streamflow conditions and performance of a wide variety of conditions were investigated in much less time and at much less risk than at full-scale conditions in the field. These tests were valuable in demonstrating the relative effectiveness of various bank protection methods. Laboratory performance of some proposed protection techniques and materials did not warrant full-scale field tests. Full-scale testing of many laboratory-tested techniques in the demonstration projects permitted field performance to be judged for nearly all of the laboratory-tested techniques. These dual observations confirmed that prototype performance can be predicted with confidence from relatively small-scale laboratory experiments.

HYDRAULIC RESEARCH

Hydraulic investigations were conducted at the U. S. Army Engineer Waterways Experiment Station (WES), Hydraulics Laboratory, and the U. S. Army Engineer Division, Missouri River (MRD), Mead Hydraulics Laboratory, to: investigate and demonstrate hydraulic processes inducing streambank erosion, study site-specific problems of interest to the Corps, demonstrate the relative effectiveness of various bank protection methods, evaluate and demonstrate new protection techniques, confirm the adequacy of some of the Corps existing design criteria, demonstrate the applicability of modifying other guidance in existing technical literature, and provide guidance and conceptual approaches recommended for design of the most promising existing and new techniques developed from the laboratory research. Additional research was accomplished at the USDA Agricultural Research Service Sedimentation Laboratory and is reported in PART XI and Appendix F.

Hydraulic Processes

The major hydraulic processes inducing streambank erosion that were identified by the literature surveys involved surface drainage, subsurface seepage, channel flow, fluctuating water levels, waves, and navigation-induced drawdown and velocities due to the displacement of large masses of water by both the propeller and moving vessel. Streambank erosion due to surface drainage can be controlled by collecting and conveying runoff into the stream at appropriate locations with conventional drainage structures. The hydraulics laboratory research addressed all of the above major hydraulic processes except surface and subsurface drainage. Particular efforts were made to address (a) flow characteristics in alluvial river bends; (b) channel flow effects and the adequacy of various bank protection techniques; (c) individual and collective effects of seepage (flow from groundwater level above stream water surface), gradual and rapid drawdown of the stream water surface, and natural and man-made waves; and (d) effects of both shallow- and deep-draft vessels on the bed and banks of navigable streams. Brief descriptions of each of the above efforts and significant findings follow and detailed presentations are provided in Appendix B.

The most intensive erosion of streambanks takes place near the exit of the bend and the relatively sharp bend in the model. Several California alluvial rivers created maximum velocities along the bank as great as 1.8 times the average channel velocity (Exhibit VI-1). This helps to explain why meanders in alluvial rivers have been observed to increase ultimately until the velocity distribution is essentially uniform in all but the exit of the bend and that they then migrate downstream only without further widening. Revetment for fixing the outer bank of a relatively sharp model bend should be extended minimum distances of one maximum water-surface width upstream and 1.5 maximum water-surface widths downstream of the bend (Exhibit VI-2). Riverbed scour in bends is probably one of the more prevalent causes of protective works failure, but none of the available methods for estimating the

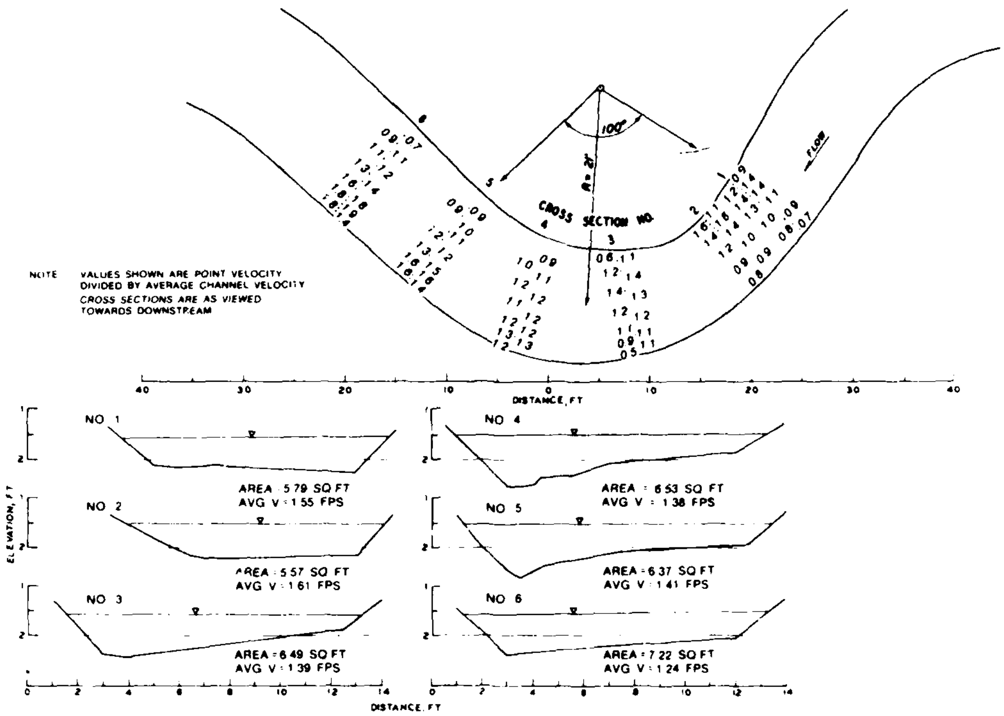


Exhibit VI-1. Velocity observations, 100-deg bend with riprap channel bottom and banks, Q = 9 cfs

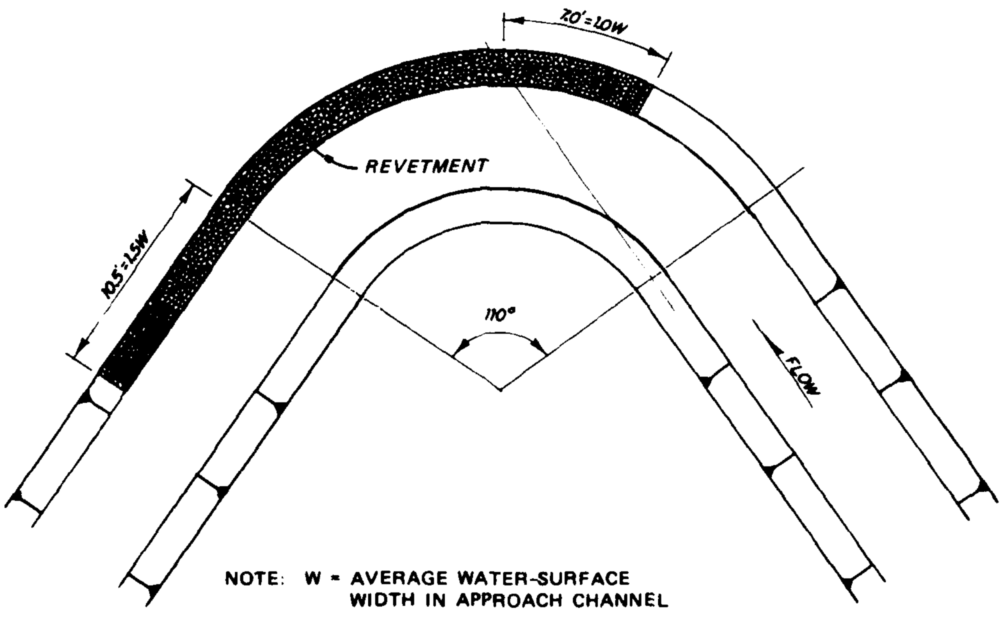


Exhibit VI-2. Recommended extent of riprap revetment for 110-deg bend

maximum depth of scour in bends have been verified to the extent that they may be used with confidence in the design of streambank protection.

Channel Flow Effects on Various Bank Protection Techniques

The cause of bank erosion at many sites can be tied directly or indirectly to the effects of channel flow. The following paragraphs discuss the effects of channel flow on eight protective techniques studied in the laboratory.

Reinforced revetment is a two-part structure comprised of a continuous stone toe-fill along the base of the slope accompanied by intermittent stone-fill tiebacks (Exhibit VI-3). The toe-fill is placed with the crown of the stone at or slightly below the normal water surface, either against the underwater bank slope or at a distance from the high bank depending upon flow conditions. The toe-fill inhibits bankline erosion for all flows at or below the normal water-surface elevation. Tiebacks are then placed at intervals equal to or less than 15 depths of flow along the toe-fill extending from the crown of the toe-fill back into the bank. The tieback prevents high flows from concentrating landward of the toe-fill and causing failure of the toe-fill when it is overtopped. The U.S. Army Engineer District, Omaha (MRO), has standardized five reinforced revetment designs because of their versatility as bank protection measures. Tests with only toe protection (riprap and gabions) indicated the need for intermittent tiebacks.

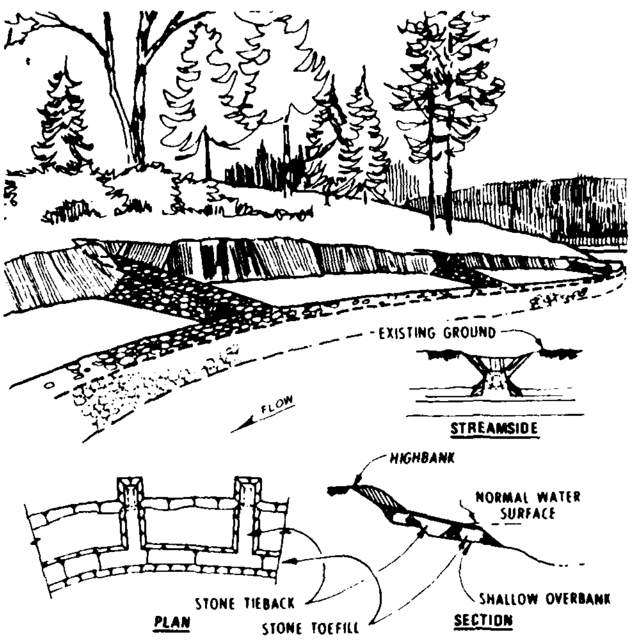


Exhibit VI-3. Reinforced revetment

Fencing can be used as a low-cost bank protection technique on small to medium size streams. Special structural design considerations are required in areas subject to ice and floating debris. Both longitudinal (parallel to stream) fence retards and transverse (perpendicular to stream) fences have been used in the prototype with varying degrees of success. A model investigation (Exhibit VI-4) and literature review of longitudinal fence retards with tiebacks were conducted to identify the following important design considerations:

(*a*) Channel gradient must be stable and not be steep (tranquil flow).

(*b*) Toe scour protection can be provided by extending the support posts well below the maximum scour expected or by placing loose rock at the base of the fence to launch downward if scour occurs at the toe.

(*c*) Tiebacks to the bank are important to prevent flanking of the fence and to promote deposition behind the fence.

(*d*) Fence retards generally reduce attack on the bank so that vegetation can establish.

(*e*) Metal or concrete fences are preferred due to ice damage and fire loss of wooden fences.

Exhibit VI-4. Laboratory model of single-row wire fence retard (before testing) in loose sand model channel

Hardpoints are an erosion control technique consisting of stone fills spaced intermittently along an eroding bank line (Exhibit VI-5). The structures protrude only short distances into the river channel and are supplemented with a root section extending landward into the bank to preclude flanking, should excessive erosion persist. The majority of the structure cannot be seen as the lower part consists of rock placed underwater, and the upper part is covered with topsoil and seeded with native vegetation. The structures are especially adaptable in long, straight reaches not subject to direct attack.

Spur dikes (impermeable) were investigated to evaluate and demonstrate their effectiveness as a bank protection technique in a concave bend of a meandering stream with noncohesive banks and insignificant suspended load (Exhibit VI-6). Several conclusions reached were:

(*a*) Spur dikes can reduce near-bank velocities to one-half of those that occur without a dike field.

(*b*) Spacing-to-length ratios as high as three may be effective in protecting concave banks with spur dikes; however, the ratio was found to vary with discharge. Spacing-to-length ratios for specific projects are best determined by previous experiences in similar circumstances or site-specific model studies.

(*c*) Spur dike root (section extending landward into bank) should be protected from scour caused by vortices set up along the upstream and downstream faces.

(*d*) The spur dike should be aligned perpendicular to the bank or current. Slight dike orientations (up to 15 deg) upstream or downstream had little effect on bank erosion in the demonstration model. Laboratory and field data existing are insufficient to conclude that dikes aligned on any acute or obtuse angle are superior or as good as those aligned perpendicular to flow.

(*e*) Aprons are effective in limiting the depth of scour at the spur dike's toe. Although the maximum scour depths and bank erosion in the demonstration model were similar,

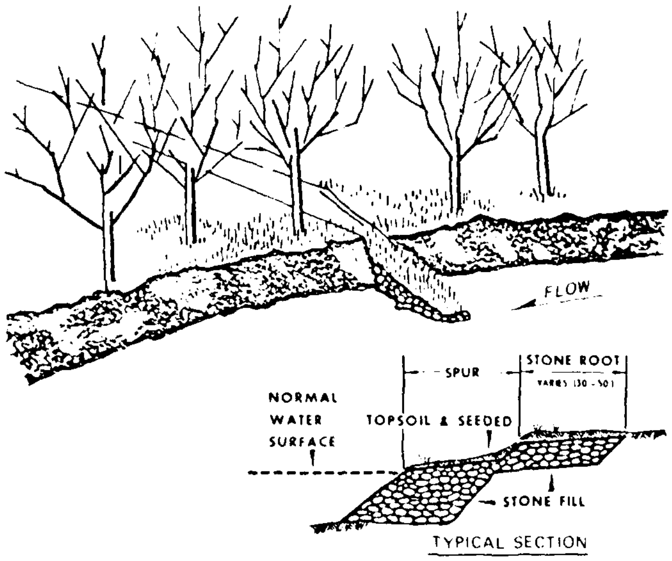


Exhibit VI-5. Perspective of hard point with section detail

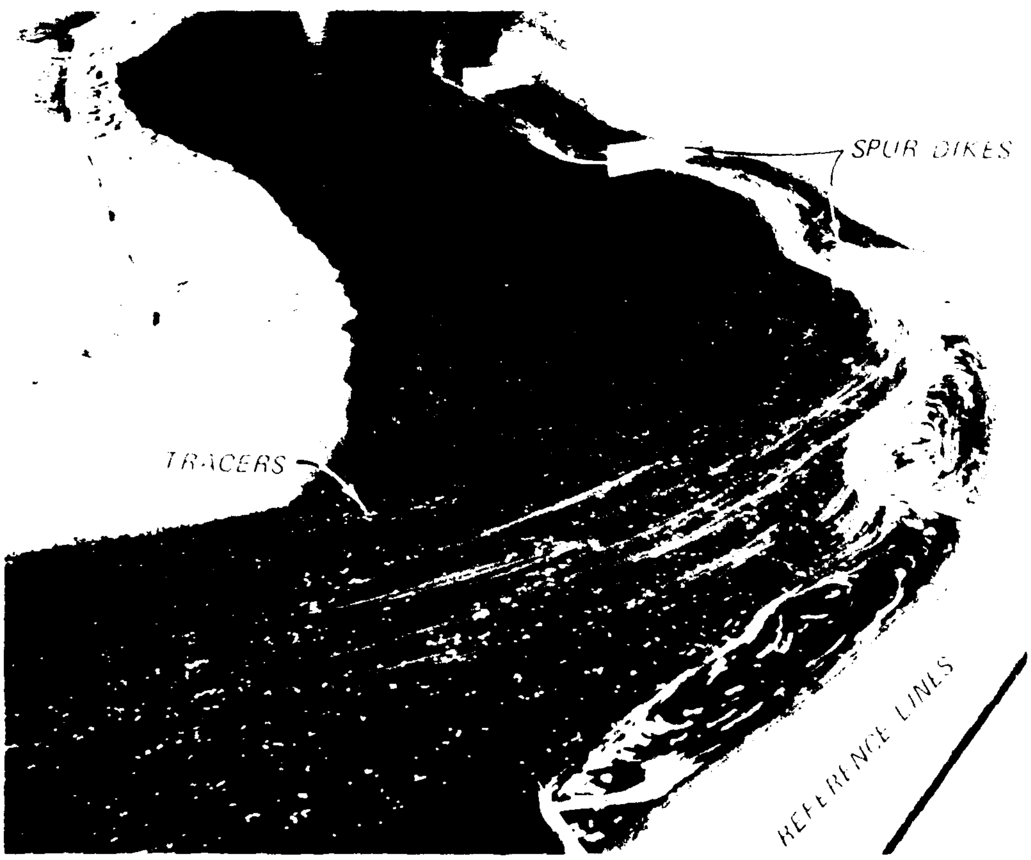


Exhibit VI-6. Spur dike model, loose sand bed, with flow patterns at beginning of test (WES Laboratory)

with and without aprons, the point of maximum scour was moved downstream from the toe of the spur dike, substantially improving the structural integrity of the spur dike.

(*f*) Development of a scour hole at the toe of the spur dike may be retarded by the formation of an armor layer. The armor layer may be composed of the very coarse fraction of streambed material which should be identified and considered in the design of spur dikes.

(*g*) Site-specific model studies will provide useful information with respect to velocity reduction against the bank and scour tendencies.

(*h*) Existing equations for prediction of scour at spur dikes are questionable for application to dikes in concave bends.

Vane dikes are low-elevation structures designed to guide the flow away from an eroding bank line (Exhibit VI-7). The structures can be constructed of rock or other erosion-resistant material, the tops of which are constructed below the normal water surface and would not connect to the high bank. Water would be free to pass over or around the structure with the main thread of flow directed away from the eroding bank. The structures will discourage high erosive velocities next to an unprotected bank line, encourage diversity of various channel depths, and protect existing natural bottomland characteristics. The findings from the model investigation of these structures include the effects of various vane dike orientation, vane dike length, and gap length.

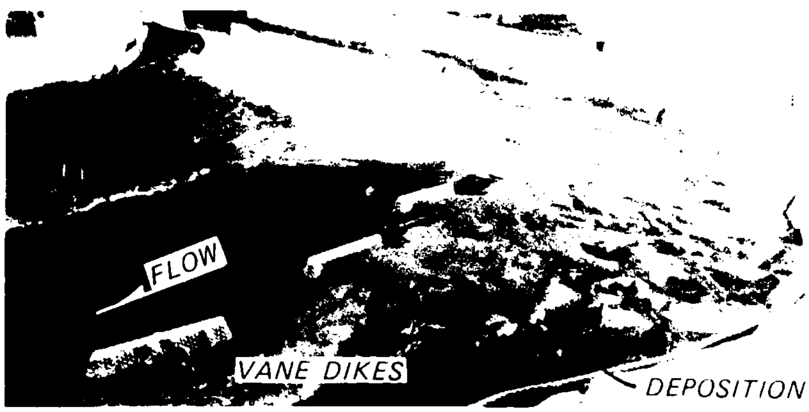


Exhibit VI-7. Vane dike model, ground walnut shell bed, during low stage portion of test run elevation 1.482 ft (Mead Laboratory)

Riprap-filled cells or grates are a relatively new bank protection concept and consist of a cellular-type containment with bottom and top openings that can be square, rectangular, triangular, etc. This concept has been used in Russia on navigable waterways to protect the zone of wave attack from erosion. The principle on which the riprap-filled cells work is that they withstand and diffuse the hydraulic forces due to waves and channel flow. The rock required in the cells should be considerably smaller than that required without the cells. A model demonstration of channel flow effects identified that the cells must be anchored if constructed of a lightweight material and that failure of the cells was mainly due to undermining of the toe of the grates.

Gabions (wire baskets filled with stone) were demonstrated to be effective for total bank protection but they were not effective as isolated hard points.

Windrow revetment is an erosion control technique (Exhibit VI-8) consisting of the depositing of a fixed amount of erosion-resistant material landward from the existing bank line at a predetermined location, beyond which additional erosion is to be prevented. The technique consists of burying or piling a sufficient supply of erosion-resistant material below or on the existing land surface along the bank, then permitting the area between the natural riverbank and the windrow to erode through natural processes until the erosion reaches and undercuts the supply of rock. As the rock supply is undercut, it falls onto the eroding area, thus giving protection against further undercutting, and eventually halting further landward movement. The resulting bank line remains in a near natural state, with an irregular appearance due to intermittent lateral erosion in the windrow location. The treatment particularly lends itself to the protection of adjacent wooded areas, or placement along stretches of presently eroding, irregular bank line. The following observations and conclusions were obtained from model investigations on windrow revetments.

(*a*) The "application rate" is the weight of stone applied per foot of bank line. The amount of stone in the windrow indicates the degree to which lateral erosion will be permitted to occur.

(*b*) Various windrow shapes were investigated in the model investigations, and a rectangular cross section was the best windrow configuration. This type of windrow is most easily placed in an excavated trench of the desired width. The second best windrow shape was found to be a trapezoidal shape. This shape provides a steady supply of stone to produce a uniform blanket of stone on the eroding bank line. A triangular shape was found to be the least desirable.

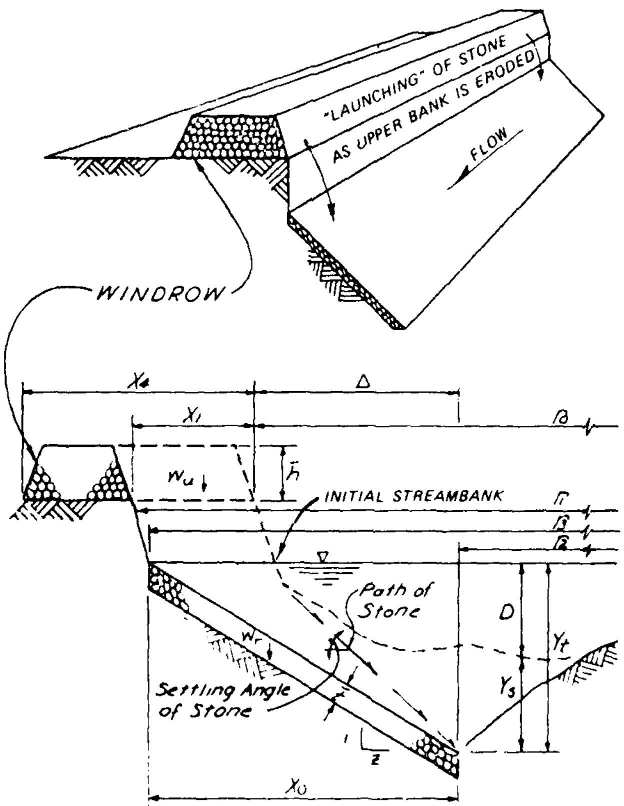


Exhibit VI-8. Windrow revetment, definition sketch

(c) The velocity and characteristics of the stream dictate the size of stone that must be used to form a windrow revetment. The size of stone used in the windrow was not significant as long as it was large enough to resist being transported by the stream. An important design parameter is the ratio of the relative thickness of the final revetment to the stone diameter. It was found that larger stone sizes will require more tonnage than smaller stone sizes to produce the same relative thickness. A well-graded stone is important to ensure that the revetment does not fail from leaching of the underlying bank material. The stream velocity was found to have strong influence on the ultimate side slope of the revetment. It was determined that the initial bank slope was on the average approximately 15 percent steeper than the final revetment slope. In general, the greater the velocity, the steeper the side slope of the final revetment.

(*d*) Studies indicated that varying the bank height did not significantly affect the final revetment; however, high banks tended to produce a nonuniform revetment alignment. Studies showed that the high banks had a tendency for large segments of the bank to break loose and rotate slightly, whereas the low banks simply "melted" or sloughed into the stream. The slight rotation of the high bank segment probably induced a tendency for ragged alignment.

Navigation Effects

The effects of shallow- and deep-draft navigation on streambed and streambank stability were investigated. The Sacramento River Deep Water Ship Channel has experienced several riprap failures along a reach of the levees of the deep-draft channel. A 1:30-scale model of the channel and a typical tanker (Exhibit VI-9) were used to investigate the causes of riprap failure and to evaluate the stability of the large riprap protection proposed for repair of the damaged sections. The model showed that the mass of water displaced by the passage of the vessel and the resulting rapid drawdown and surge or bore

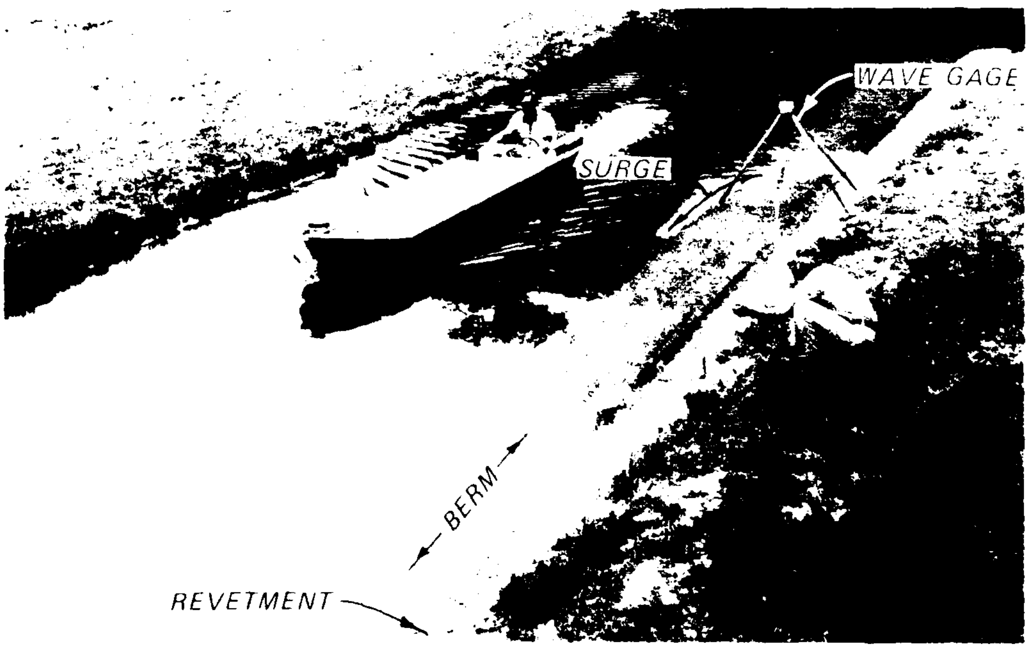


Exhibit VI-9. Sacramento River Deep Water Ship Channel model, sand bed, with tanker traveling at 8.8 mph with 40-ft depth of water over the berm (WES Laboratory)

are the probable causes of the riprap failure. The site-specific relations determined between channel size, ship size, ship speed, rapid drawdown, and relative depths of draft and water showed that a reduced vessel speed or an increase in channel size will significantly reduce the drawdown and rapid surge in the channel. The model tests determined the proposed replacement riprap was stable.

Streambed stability in and around navigation locks and dams and berthing areas has become of concern on the Nation's waterways due to the large horsepower vessels in operation today. A 1:20-scale model (Exhibit VI-10) typical of shallow-draft inland navigation tows was used to determine the conditions required for stable riprap protection of the streambed as a function of depth and towboat size. Relations between stable rock size, depth, and size of towboat with two propellers were determined and found to be in fair agreement with results of a design technique for a single-propeller tow found in the engineering literature.

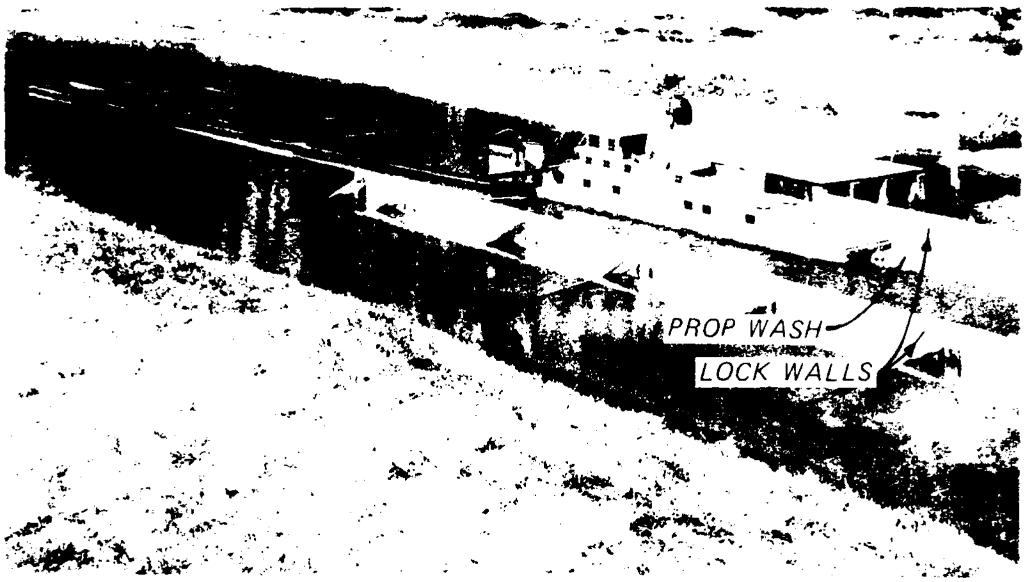


Exhibit VI-10. Shallow-draft inland navigation model, fixed banks, with tow for study of riprap size required on channel bottom in maneuvering areas (WES Laboratory)

Seepage, Drawdown, and Wave Effects

The individual and combined effects of seepage, drawdown, and waves were investigated and demonstrated on both protected and unprotected streambanks. Full-scale tests (1:1-scale model: prototype) of riprap overlying granular filters, over a woven filter fabric, a nonwoven filter fabric, and a layer of sand on top of a nonwoven filter fabric demonstrated adequate filters are needed for the gradation, slope, and bank material tested. Exhibit VI-11 shows the riprap over granular filters being exposed to nonbreaking waves. The unprotected streambanks and riprap-without-a-filter-protected streambanks were unstable when subjected to only seepage due to a relatively low potential energy of 1 ft of differential between the groundwater level in the bank and the water surface in the stream, or to the relatively high kinetic energy environment of waves. Test results with riprap designed in accordance with the Corps of Engineers Technical Letter 1110-2-222 varied from plan to plan; but the results showed that adequate filters, either granular or fabric, are needed between the protection and the noncohesive bank material.

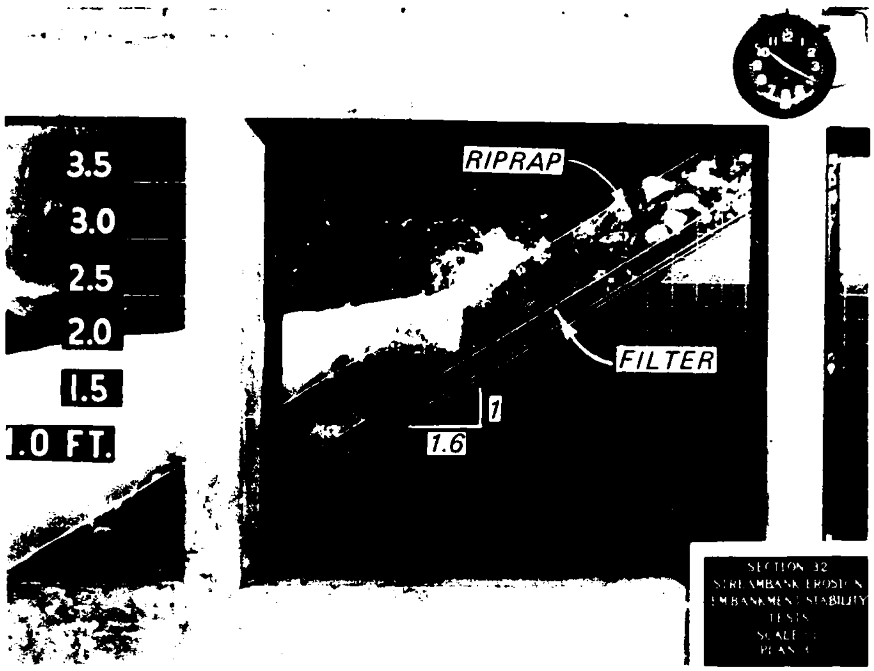


Exhibit VI-11. Seepage, drawdown, and wave effects model (WES Laboratory). Riprap over 2-layer granular filter on uncompacted sand bank being exposed to nonbreaking waves (0.2- by 0.2-ft grid)

When filter fabric is being used in lieu of granular filters in such locations, care must be taken to ensure that the fabric is not punctured and that the sides and toe of the filter fabric are entrenched or otherwise sealed to the bank so that leaching of the bank material does not occur in these areas. Methods of attaching adjacent sections of filter fabric together were not addressed in these tests, but it is obvious that care needs to be taken to ensure that properly sewn, overlapped, or welded seams are used to prevent leaching of the streambank material through the seams. The tests did indicate that noncohesive streambank material tends to migrate downslope beneath the filter fabric when it is exposed to wave attack and or seepage flow out of the streambank. This downslope movement of streambank material (sand) did not occur beneath the granular filters when the test sections were exposed to the same wave and or seepage and drawdown flow conditions.

Test results confirm experience that riprap stability increases with increasing thickness of riprap because more protection material is available to armor exposed areas that occur without exposing other areas of streambank. Thicker layers of riprap also provide better streambank protection from wave attack in that more wave energy is dissipated before it reaches the filter and streambank.

Both two- and three-dimensional wave-stability model tests were conducted, at a scale of 1:4 (model:prototype), to test a new bank protection concept referred to as riprap-filled cells. It consists of a lattice of cells (open at top and bottom) filled with small stones and is applicable to areas where large riprap is not readily available or economical. Much smaller riprap can be used to stabilize streambank slopes with the riprap-filled cells. Cubic-foot cells (prototype size), half-full and full of a riprap composed of crushed stones which ranged in weight from a maximum of 4.6 lb to a minimum of 0.6 lb withstood a wave environment that would require a riprap gradation with individual stones ranging from a maximum of 135 lb to a minimum of 4.25 lb for stability when used alone. The riprap-filled cells

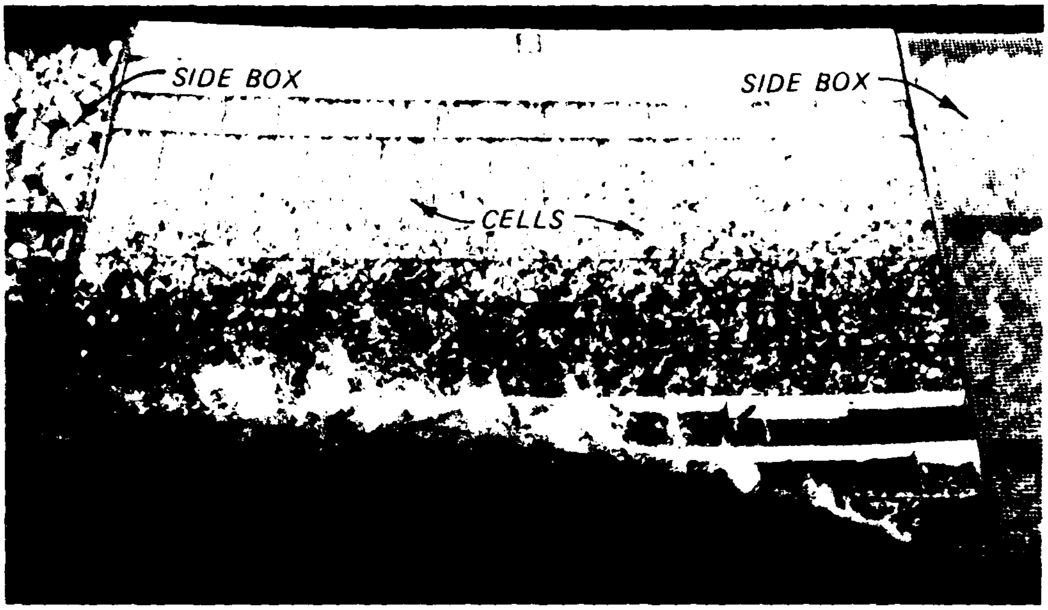


Exhibit VI-12. Riprap-filled model cells on fixed bed being exposed to 6.0-sec, 2.0-ft nonbreaking waves with a 30-deg angle of model attack (WES Laboratory). Side boxes prevent unnatural wave attack due to end effects. The 6- by 12-in. model cells represent 2- by 4-ft prototype cells

were exposed to prototype equivalent 2.0- to 6.0-sec, 1.0- to 3.0-ft nonbreaking waves for angles of wave attack of 90, 60, and 30 deg. Exhibit VI-12 shows the rectangular cells being exposed to the 30-deg angle of wave attack.

The cell depth needed for stability of the riprap fill increases with increasing steepness of the streambank slope and increasing dimensions of the individual cells. More details and guidance for selection of cell depth relative to the streambank slope and the interaction of the riprap-filled cells with the streambank are given in Appendix B.

GEOTECHNICAL RESEARCH

Selected aspects of streambank erosion and control were investigated for the Section 32 Program at the WES Geotechnical Laboratory, supplemented by contract studies at the University of California, Davis, and further supported by academic and technical advisors. The laboratory research addressed the influence of soil properties on erodibility and bank stability; procedures were suggested for including erosional effects in bank stability analyses. Materials and construction methods previously developed in surface stabilization research were adapted to bank protection using laboratory modeling techniques and experimental field installations. The research and significant findings are described in Appendix C. Geomorphological and waterborne geophysical onsite field studies, related to causes and mechanisms in the streambank erosion processes, are discussed in PART VII.

Prediction of Soil Erodibility

The erosion characteristics of cohesionless soils, which are controlled by gra   .ional forces, are fairly well understood. However, the development of a procedure for streambank stability analysis has

been stymied, in part, by a lack of understanding of the erosive characteristics of cohesive soils, which are controlled by physical and electrical phenomena. Analyses of laboratory test results obtained using a flume and rotating cylinder apparatus at the University of California, Davis, revealed quantitative relationships among critical tractive shear stress, electrical properties, and rates of erosion for saturated, remolded cohesive soils using distilled water as the eroding fluid. Correction factors were obtained for the effects of remolding and salt concentrations of the eroding fluid. The laboratory relationships can be adjusted by the correction factors to estimate erodibility of saturated undisturbed cohesive soil subjected to tractive shear stress by river water for use in bank stability analyses.

Laboratory measurements of soil erosion characteristics under hydraulic flows were attempted in an experimental self-contained laboratory recirculating tilting flume, Exhibit VI-13, by applying hydraulic shear stress to a soil sample. The research tests conducted in the recirculating flume involved the use of experimental laboratory equipment and procedures. Field validation is required to establish the reliability of the laboratory results and the conceptual approaches.

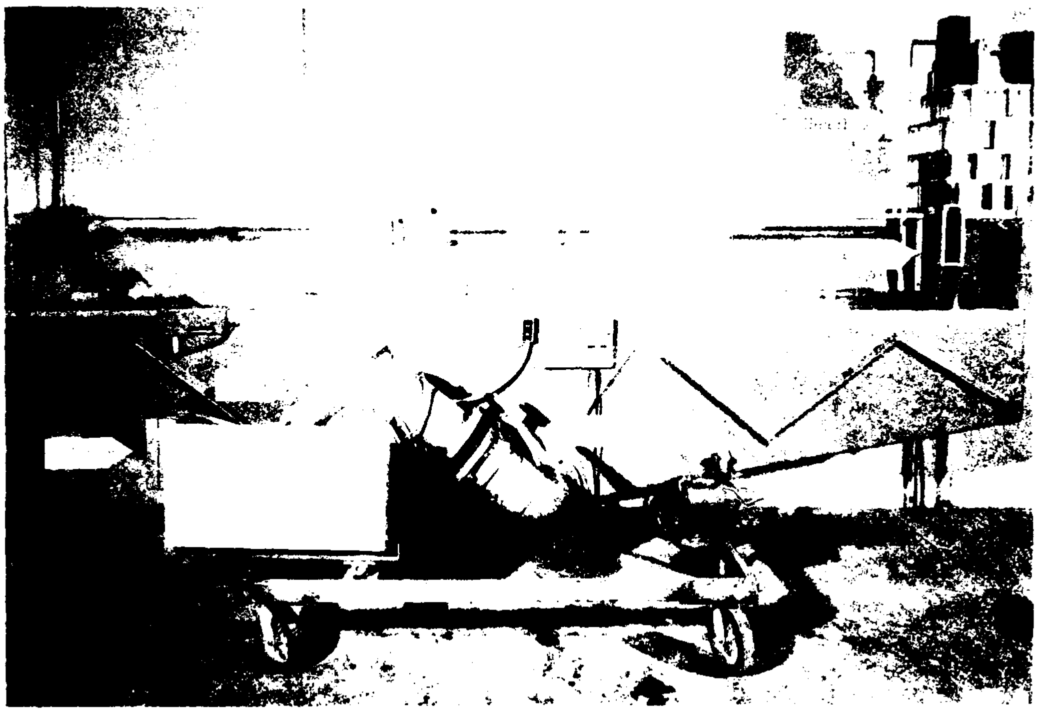


Exhibit VI-13. Laboratory recirculating tilting flume to qualitatively measure soil erosion

Procedure for Evaluating Streambank Stability

The analysis of streambank changes caused by soil erosion is analogous to conventional stability analysis of an excavated slope. Bank recession with time can be estimated by using a procedure as shown in Exhibit VI-14. This conceptual procedure combines erosion characteristics and conventional soil parameters used in limit equilibrium slope stability analyses. Erosional changes in geometry, such as toe recession and or bed degradation, can precipitate slope failure with resulting top retreat of the streambank. The bank recession with time is equal to the cumulative bank recession caused by erosion

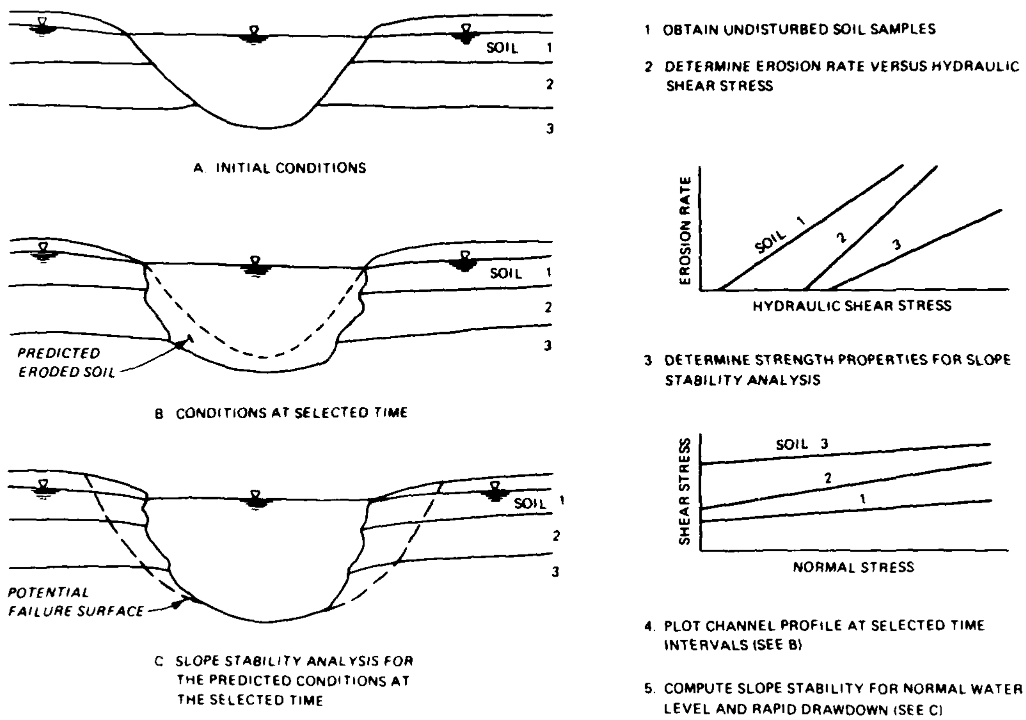


Exhibit VI-14. Procedure for evaluating streambank stability

and slope failures. The analysis of a generalized streambank section evaluated for bank and bed erosion and slope stability under normal flow conditions and during the passage of floods is illustrated by an example problem in Appendix C.

To evaluate streambank stability, it is necessary to estimate changes in geometry due to erosion and slope movements. Bank recesssion or bed degradation estimated from the laboratory relationships developed for tractive (current) erosion is an approximation because it does not take into account such things as accretion along the banks, secondary currents, freeze-thaw, and bed aggradation as eroded soil from upstream is deposited at the reach of the river under consideration. A sediment transport analysis which includes hydraulic sorting and armoring would be necessary to include the effects of deposition. In addition to changes in geometry due to current erosion, bank failure causes changes in geometry. Bank failure results when the induced shear stresses exceed the shear strength of the bank soils. Increases in shear stress can result from increase in slope height or steepness, increase in external loads (surcharge), and rapid drawdown of the river. Decreases in shear strength of the soil can result from an increase in pore-water pressure, soil expansion, or shear movements.

Simple homogeneous banks are more easily handled by the suggested procedure for evaluating streambank stability. The simplification of procedures common in conventional soil mechanics practice permits complex heterogeneous banks to be evaluated. The suggested procedures are slightly more complex and unique only in that the erodibility of the bank soils is incorporated into the assessment of equilibrium and/or potential bank failure.

Expedient Methods for Self-Help Projects

Materials and construction techniques previously developed in surface stabilization research were investigated for potential applications in preventing erosion of upper and lower banks. Materials and

innovative methods for placing these materials on streambanks were selected primarily for cost-effectiveness and use by private landowners with only limited resources available, such as hand labor and light equipment. These investigations and significant findings are described in Appendix C.

When large top-bank areas are stripped of natural vegetation, spray-on soil stabilizers can be used effectively as protection from erosion by rainfall and wind until vegetation can be reestablished. Five types of spray-on materials evaluated included a polyvinyl acetate latex water emulsion that cures into a durable surface film; a copolymer emulsion of acrylate and methacrylates that cures into a durable surface film; an acrylic that forms a thin hard surface; cutback asphalt that penetrates the soil and leaves a tough hard surface; and an adhesive based on resin from the semichoking of fuel shale and caustobioliths. These materials were applied at various application rates on flat and sloping reseeded areas to determine erosion resistance and to reestablish vegetation. From these tests, synthetic latex and emulsion materials were more effective.

An aluminum honeycomb grid material pressed into native soil and planted with vegetation cover demonstrated potential usefulness as a soil confinement system to facilitate establishment of permanent upper bank erosion control in combination with vegetation cover. The system was evaluated for effectiveness and durability in controlling erosion, ease of placement, and cost. This grid-vegetation system is suitable where the more expensive erosion control measures are not justified, but where something more substantial than vegetation alone is required.

Portable rigid metal mats and flexible membranes commonly used as expedient surfacing materials were evaluated by testing conceptual protective systems in a hydraulic model. Protective schemes were placed along the outside curve in the hydraulic model channel where erosion was the most severe. Impervious flexible membranes were laminated vinyl and neoprene-coated nylons and reinforced plastic laminate of a nonwoven grid of polyethylene ribbons. Filter fabric materials were direct-spun polyester filament; two continuous filaments in random arrangement (100 percent polypropylene and a polypropylene core surrounded by nylon sheath); and a vinyl-coated polyester. Based on costs and these model tests, membrane materials were selected for full-scale field tests to provide three degrees of protection: a membrane blanket for light duty; membrane-encapsulated soil layers (MESL) constructed as slabs for medium duty; and a stepped-MESL construction for heavy duty.

WES test sites on Durden Creek and the Big Black River were used for evaluations of materials selected from the hydraulic model tests; two experimental membranes and two filter fabrics were also selected for field tests and comparison purposes.

The Durden Creek site was selected to determine construction, placement, and anchor techniques for small sections of materials. The silty clay bank along this reach had been eroded previously by streamflows that overtopped and submerged the banks for periods up to 6 hr and caused fluctuations in water levels as much as 7 ft during periods of heavy rain. These extreme flow conditions occurred several times during the period observations were made of the test materials. The materials were placed 2 ft above the top of bank and extended below the low-water elevation (Exhibit VI-15). Seven different test items were constructed, each approximately 17 ft wide and 22 ft long, as follows:

(*a*) A stair-stepped MESL with laminated vinyl-coated nylon membrane as the encapsulating material installed where the bank had caved vertically.

(*b*) Four "blanket" items; one each of laminated-vinyl and neoprene-coated and two Hypalon-coated nylon membranes draped over the sloped bank area anchored in ditches.

(*c*) A MESL item with the laminated vinyl-coated membrane as the encapsulating material.

(*d*) Filter fabric covered with riprap (a standard for comparing the performance of all test materials).

Exhibit VI-15. Test materials installed at Durden Creek

During the limited monitoring period from August 1979 through December 1980, stream velocities up to 3.9 fps and discharges up to 280 cfs tested the protection under maximum flow conditions. Two minor problems were ballooning of the membrane on the stepped-MESL item and deterioration of all sandbags; these construction problems were solved before tests were initiated at the Big Black River test site. Observations during flood conditions (Exhibit VI-16) indicated that all of the test sections on Durden Creek performed satisfactorily.

Exhibit VI-16. Flood conditions at test site on Durden Creek

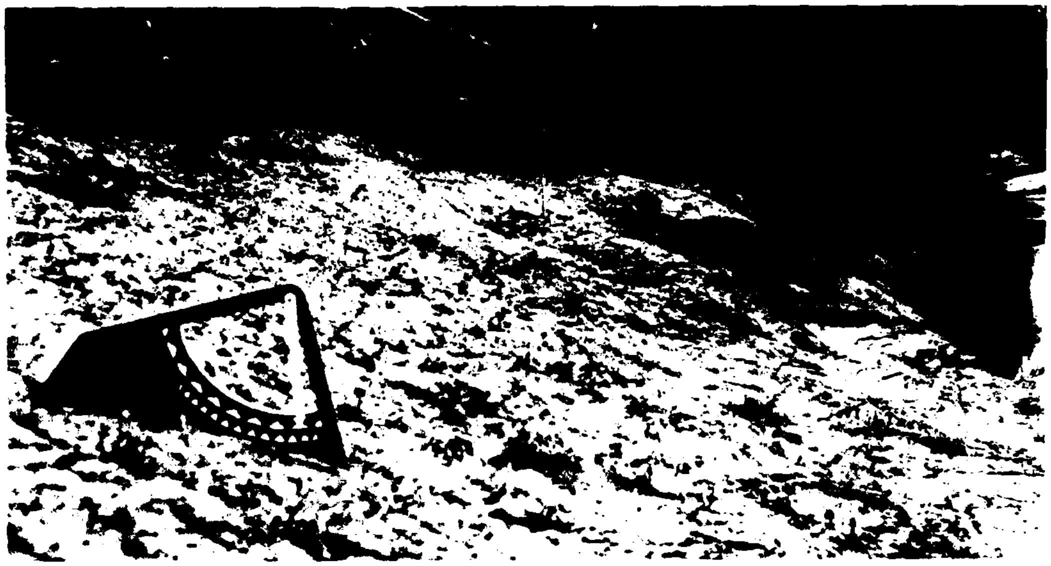


Exhibit VI-17. Big Black River test site. View looking upriver before installation of materials

The bank at the Big Black River test site had been denuded of most vegetation by rapid and frequent large fluctuations of river stages (Exhibit VI-17). Small trees, grass, and weeds existed near the top of bank. The bank was steeply sloped and the upper bank was near vertical, 6 to 10 ft in height. The top bank soil was clay underlain by sandy clay. The groundwater was normally about 1 ft higher than the river.

The test area was reshaped to a more uniform and slightly flatter slope for installation of test materials. Test items illustrated in Exhibit VI-18 were constructed approximately 22 ft wide (parallel with water flow) and 42 ft long (perpendicular to water flow) of the following materials: riprap placed

Exhibit VI-18. Test materials installed at Big Black test site

on filter fabric; blankets of Hypalon, laminated vinyl, and neoprene-coated membranes; MESL constructed with laminated vinyl-coated nylon; riprap placed on filter fabric (standard comparison item); and stair-stepped MESL constructed with laminated vinyl-coated membrane.

The bank area below the toe anchor ditches was covered with 10 to 12 in. of riprap placed on filter fabric. This area was approximately 6.5 ft wide and extended the length of the test site.

All test items on the Big Black River protected the banks from erosion during bank-full stages that produced maximum velocities of 3.0 fps and discharges of 9300 cfs (Exhibit VI-19); however, flood conditions overtopping the banks for an extended period of time (Exhibit VI-20) caused banks not only at the test site but throughout the river basin to fail during periods of rapid drawdown. Deep-seated bank failure at the test site caused the displacement of test materials and anchor ditches. These field tests indicated that membranes can be used to prevent erosion when installed as blankets and as slab or stepped-MESL sections but must be placed on stable banks. The blanket method can be used where the banks require a light protective surface to prevent erosion by current and wave action. The MESL slabs can be used as a medium-type protection when loose surface conditions exist on banks. The stepped-MESL can be used as heavy duty protection in areas where severely eroded and caved banks are nearly vertical as this method eliminates extensive grading and shaping of the banks. The field tests demonstrated that the membrane materials are easily constructed and cost-effective for expedient protection.

RIGHT:

Exhibit VI-19. Bank-full stage looking downstream at the Big Black test site

BELOW:

Exhibit VI-20. Big Black test site covered by 2 ft of water during flood of 31 March 1980

PART VII: CAUSES AND MECHANISMS OF STREAMBANK EROSION AND BANK FAILURE

GEOMORPHOLOGY OF STREAMBANK EROSION

Streambank erosion is only one of many identifiable mechanisms that can lead to bank failure. Because erosion is a common mechanism and because of the complexity of the associated processes, it is emphasized in the following discussions. The term "bank failure," as used herein, infers a sufficiently large displacement of a streambank so as to be of concern to a landowner. The terms "erosion" and "deposition" are the removal and the accumulation, respectively, of soil particles due to water action. The term "natural erosion" identifies the expected erosion that occurs because of time-dependent climatic and geologic factors. The term "accelerated erosion" identifies the erosion that exists because of human actions or atypical natural occurrences.

Natural Erosion

In a fluvial system, a stream flows through erodible sediments so that the channel is a naturally derived consequence of precipitation, drainage basin, and sediment characteristics. The natural fluvial channel continuously changes location (as noted in Appendix C) by natural erosion processes. The geometry of a specific stream channel may also be controlled to a large extent by natural hard points, that is, by geologic formations that are highly resistive to erosion.

Accelerated Erosion

Although the form of a fluvial stream channel is inherently unstable due to natural erosion, these channels tend toward a quasi-equilibrium geometry when viewed in a time frame comparable to human activities. The quasi-equilibrium form, as noted in Appendix C, is described by variables relating to alignment, cross-sectional shape, and longitudinal profile. The dominant factors that determine channel form, given a specific climate and geologic circumstance, are the amount and variation of streamflow and the amount, variation, and character of material available for transport. Any atypical natural occurrence or any human action that influences streamflow or material transport causes accelerated or unexpected erosion to some greater or lesser extent as the stream forms a new quasi-equilibrium channel.

Site Investigations

The historic analysis and other investigative procedures described in Appendix C are of great importance in bank protection design. The findings should answer the following three questions.

- To what extent does streambank erosion influence bank instabilities that exist at the site of interest?
- To what extent can local streambank erosion be attributed to accelerated rather than natural erosive processes?
- What is the cause of local accelerated erosion and bank instability?

An overview of mechanisms, including erosion, that are of potential site-specific significance as far as bank stability and protection are concerned is presented in the following paragraphs; a site investigation and analysis should, to the extent possible, indicate the historic, current, and future significance of each applicable mechanism.

CAUSES OF STREAMBANK FAILURE

Bank failures sometimes occur through the intermittent or continuous removal of soil particles from the bank surface; however, failures also occur as a single movement of a large mass of soil and as a sequence of failures of smaller segments of bank material. As noted in Appendix C, a single identifiable mechanism is rarely the cause of even a site-specific bank failure; instead, several conditions occur in such a manner that their combined actions cause failure. For descriptive purposes potential mechanisms are categorized here according to three general circumstances:

- Mechanisms that cause displacement of soil particles along the bank surface (Exhibit VII-1).
- Mechanisms that transport material away from the bank (Exhibit VII-2).
- Mechanisms that directly influence the structural integrity and stability of streambanks (Exhibit VII-3).

Soil Particle Displacement

At a specific site, only one or two mechanisms, noted in Exhibit VII-1, may significantly contribute to the erosion of the bank surface and bank protection may be designed simply to control the displacement of surface soil particles. For example, where floating ice and debris are gouging the bank, some type of boom system might be devised to eliminate the problem. The design must not aggravate or create an alternate mechanism; for example, were the above boom to cause high flow velocities and turbulence along the bank increasing the erosion of soil particles, then the boom would be an unsatisfactory solution. At many sites the displacement of particles is attributed to combinations of numerous mechanisms. The problem of controlling soil particle instability then becomes considerably more complex.

Sediment Transport

Of the four mechanisms listed in Exhibit VII-2 (gravity, human action, water flow, and wind), transport by water dominates the erosion processes. The water or hydraulic transport is regarded in three parts—streamflow, overbank flow, and seepage flow. Each potential bank failure is site-specific; consequently, the dominance of one mechanism in a general sense does not rule out the significance of complementary mechanisms. However, except for certain human activities and wind action, material originally displaced by gravity, overbank drainage, or seepage normally remains at the site until it is removed by streamflow transport. Erosion can be reduced by controlling the transport mechanisms; for example, drainage structures along the top bank can reduce the quantity of overbank flow thereby decreasing erosion capacity. Complementary vegetation on the bank will enhance soil particle stability.

Massive Bank Failure

Except for unusual circumstances, surficial erosion, as noted in Exhibit VII-3, is not in itself a bank failure but can contribute to collapse of a relatively large segment of bank. Two factors make streambank failure a difficult geotechnical problem. First, variations in surface and subsurface flows and in soil moisture conditions are normally more severe along streambanks than at locations remote from a stream; and second, the economic circumstances rarely justify the detailed site-specific studies needed to adequately describe the soil and groundwater conditions.

Mass failure of an initially stable bank, as described in Appendix C, is brought about by changing conditions either at the surface or within the mass. Erosion contributes to the failure process by eroding initially stable slopes into unstable banks, and by removing failed debris

from the stream channel so that a succession of failures can occur. Local precipitation, water table, and stream stage variations also contribute to the failure process by altering groundwater conditions within the mass. Examples of surface effects, moisture variation, and miscellaneous actions that tend to make streambanks structurally unstable are listed in Exhibit VII-3; these are discussed below according to four bank categories -- rock, cohesionless soils, cohesive soils, and heterogeneous deposits. The consequence of dominant mechanisms and the nature of failure processes are similar within each category, yet remarkably different between categories.

In using categorical descriptions the continuous range of physical properties of naturally existing bank materials must be recognized. For example, homogeneous streambank made up of a single sediment type is extremely rare in nature. Numerous classification systems are used to separate clay, silt, sand, and gravel grain sizes (see PART XIV); for descriptive purposes soil mixtures of gravels, sands, and silts are cohesionless while mixtures containing clay are usually cohesive.

Comments concerning each of the four categories in relation to descriptive material listed in Exhibit VII-3 are as follows:

Rock banks are normally stable but are subject to gradual surface deterioration through erosive mechanisms and to sudden intermittent mass failure brought about by any one, or a combination of several, of the mechanisms listed in Exhibit VII-3.

Cohesionless banks in nature are heterogeneous deposits, usually highly stratified. The angle of repose, as shown in Appendix C, is small (as low as about 20 deg) for soils made up of fine well-rounded particles and large (to values greater than 45 deg) for coarse angular particles. During field inspection, care is required in order to differentiate between the true angle of repose which is independent of the height of bank material and a temporarily stable steeper slope due to capillarity, soluble bonding, or plant root structure. The finer grained cohesionless soils drain more slowly than the coarse grained and are therefore more susceptible to failure.

Cohesive banks are analytically complex as shown in Appendix C. Since an extremely thin cohesionless layer or seepage plane can entirely change the failure mechanism, particular care in field inspection and caution in analysis are necessary. Because of low permeability these soils tend to drain slowly during rapid lowering of the stream water level and become unstable. Unlike cohesionless banks, height of bank is an important variable in stability analysis of cohesive banks -- high banks tend to be more unstable.

Nonhomogeneous (heterogeneous, interbedded, stratified, etc.) banks are most common in nature -- no combination or orientation of rock, cohesive or cohesionless material is precluded by natural processes although common regional structures exist. As noted in Exhibit VII-3, any one of all the listed failure mechanisms (or combinations of several) could apply to a nonhomogeneous bank. Finely detailed field investigation is necessary.

Observed Bank Failures (Section 32 Projects)

The causes of failures of unprotected streambanks at the 68 demonstration and 50 existing projects in the Section 32 Program were observed and reported by many different people without the benefit of uniform evaluation procedures and classifications of failure phenomena. The various descriptions of the failure causes given in Appendices D-H have been separated into the following groupings, which represent a number of single or combined, but not all, causes described above.

Streamflow

- Streamflow over highly erodible soils.
- High-stage streamflow against concave bank of channel bend.
- High-stage streamflow through a relatively straight reach.

Water-surface displacement
- Wave action.
- Water-level fluctuations.
- Sloughing on a falling stage.

Channel bed degradation
- Channel alignment or flow change causing increased slope and velocity.

Water flow over and through bank
- Overbank drainage.
- Piping.
- Seepage.

Temperature and debris action
- Freeze-thaw cycle.
- Ice and debris attack.

EFFECTS OF HUMAN ACTIVITIES AND MAN-MADE STRUCTURES

Local human actions can influence every surface displacement mechanism (Exhibit VII-1), transport mechanism (Exhibit VII-2), and failure mechanism (Exhibit VII-3), either inadvertently or by design. In fact, deliberate actions chosen to inhibit one or more of these mechanisms (without enhancing others) constitutes a bank protection plan. For fluvial streams, the mechanism most severely influenced by human activity and the one having basin-wide impact on bank failure is streambank erosion (surficial deterioration). Consequently, site-specific actions are not further pursued here although they are addressed in PARTS X-XIII in a project-by-project sense. Instead, this discussion is limited to broad human activities that influence accelerated erosion which, in turn, can lead to bank failure.

General Trends

As noted in Appendix C, the dominant channel-forming variables relate to streamflow and sediment transport. For streamflow, the peak discharge and the shape of the discharge hydrograph are dominant factors. For sediment transport, the properties of the bed, banks, and transported material are important as well as are the rate and amount of material removed from overall land surface by drainage into the stream.

Because of the interdependence and variability of the many factors that determine channel form, every stream is a unique and special case. General observations of stream response are given in Appendix C. Streams commonly tend to respond as follows:

Factor	Change of Factor	Common Response in Channel: Action	Common Response in Channel: Amount
Peak flow rate (quantity)	Increase	Degradation	Strong increase
	Decrease	Aggradation	Weak increase
Flow duration (high flows)	Increase	Degradation	Strong increase
	Decrease	Aggradation	Weak increase
Sediment yield (basin)	Increase	Aggradation	Weak increase
	Decrease	Degradation	Strong increase
Sediment transport capacity (stream)	Increase	Degradation	Strong increase
	Decrease	Aggradation	Weak increase

Streambed degradation and aggradation indicate that a stream is tending to re-form its channel; changes in channel alignment and resulting bank instabilities can be expected in either circumstance. Evaluation depends on the location of the site along the stream, for example, above or below a dam.

Specific Actions

Effects of prominent human actions are rated against the above stream tendencies as follows:

Agriculture or similar activity involving land-use changes may affect any of the primary factors depending on the crops, ground cover, and farming methods used. The general tendency resulting from agriculture is toward increased peak flows, insignificant flow duration change, and increased sediment yield. The stream tendency is toward erosional activity; bed degradation will occur if increased peak-flow effects dominate in relation to sediment yield and aggradation if sediment yield dominates.

Urbanization normally causes substantially increased peak flow (sediment yield may increase or decrease depending on prior use); the consequence is a strong tendency toward bed degradation and active erosion.

Reservoir operation sequences tend to reduce peak flows and sediment yield and extend flow duration for reaches within their influence; the consequence is aggradation for streams in which flow dominates and generally degradation whenever sediment transport is more significant. Erosional activity tends to increase.

Reduced dam releases may produce aggradation in an outlet channel whenever the resulting flows are insufficient as far as removing sediment inflow from tributary streams. Conversely, the tributary stream may experience severe degradation and head-cutting during these periods of low main-stem flows, particularly when the tributary streamflow is concurrently high. As noted in Appendix C, changes in main-stem stages or streambed elevations tend to be reflected as aggradation or degradation, and accompanied by erosional activity, in the tributary channel.

Mining from the streambed reduces local sediment transport which may produce a tendency for degradation downstream. Gravel mining removes the channel armor layer which, conversely, tends to increase sediment yield.

Vessel traffic on the stream tends to increase sediment yield from the banks due to wave action and enhances erosion and transport along the bed due to propeller wake turbulence. Commonly, little change in either aggradation or degradation of the streambed occurs, although there is a small increase in local sediment transport rate.

Channelization commonly increases peak flows to a greater or lesser extent depending on design and appurtenant structures. Degradation may extend upstream and into tributary stream channels and increased sediment yield may cause aggradation downstream.

Exhibit VII-1

SURFICIAL BANK DETERIORATION MECHANISMS

Mechanism	Description
Abrasion	Solid materials carried by wind or flowing water collide with and dislodge surface soil particles. Abrasion also occurs during shifting of winter ice covers.
Biological (Animals)	Examples are bank surface destruction during overgrazing and by animal burrows and trails.
Biological (Vegetation)	Vegetation normally is conducive to surficial stability; exceptions occur during decay of root material and by tree falls or vegetation patterns that concentrate or cause turbulence in overbank flows or streamflows.
Chemical	Water and acids in water affect cohesive and other types of particle-to-particle bonding; bank material is removed by dissolution.
Debris	Debris gouges, or scrapes material from, bank surfaces as well as causing turbulence and flow concentration.
Flow (Water)	Soil particle removal by overbank flows and streamflows is a major cause of bank surface deterioration. Quantity of flow, transport capacity (see Exhibit VII-2), turbulence, secondary currents, and wave action (see description below) contribute to the rate and location of surficial particle removal. Seepage flows remove surface particles as well as contributing to mass bank failures (see Exhibit VII-3).
Freeze-Thaw	Cyclic temperature changes cause fracture due to excessive contraction and expansion and spalling due to successive freezing and thawing of moisture within the bank.
Gravity	The stable slope of a cohesionless bank corresponds to gravitational stability; for steeper slopes, surface particles roll downslope (raveling).
Human Actions (on Bank)	Certain human actions attack the bank--loosening the bank surface material by farming or other mechanized operation is one example. Other actions may influence natural mechanisms--the destruction of a protective vegetation cover by livestock overgrazing is one example. Many actions are possible.
Human Actions (Stream Channel)	Examples of direct actions are dredging and sand or gravel mining of channel sediments. Examples of indirect actions are structures and vessel propeller motion that cause turbulence in the streamflow. Many actions are possible.
Ice	Ice contributes to abrasion and debris (see descriptions above). Ice jams restrict a channel and affect stream and overbank flows.
Precipitation	Surficial destruction occurs due to impact by rain or hail as well as during periods of high streamflows and overbank flows.
Waves	Waves due to wind or stream vessel traffic cause surficial deterioration of the bank near the stream water surface.
Wet-Dry	Alternate wetting and drying cause stress and chemical effects (see description above) that result in surface soil particle loosening.
Wind	Surface deterioration by wind is normally small as compared with water flow; however, waves due to wind (see description above) contribute to surficial deterioration.

Exhibit VII-2

SEDIMENT TRANSPORT MECHANISMS

Mechanism	Description
Gravity	Gravity (see Exhibit VII-1) is an intermediate means for transport because either materials are removed from the site by other mechanisms or transport ceases due to accumulation.
Human Action	Direct transport, such as occurs during local dredging or during mining for sand or gravel, is a site-specific event. Indirect actions are those that either enhance or inhibit natural transport and may either be site-specific or, whenever the action significantly affects streamflow transport, influence erosion at numerous sites along the stream.
Water Flow	Transport by flowing water (hydraulic transport) is the most effective natural transport mechanism as far as streambank erosion is concerned. Hydraulic transport is categorized as stream, overbank, and seepage transport. *a.* Transport by streamflow is enhanced by high flow rates and velocities and by low entering sediment concentrations. Whenever the transport capacity is exceeded, the excess material is deposited and aggradation occurs; conversely, whenever transport is below capacity, material tends to be eroded from the streambed and banks and degradation occurs. Streamflow is determined by drainage basin, rather than local, hydrologic events. *b.* Overbank transport, which is a major factor in sheet and gully erosion, is hydraulically similar to stream transport. However, local rather than basin-wide hydrologic events are of dominant concern in overbank transport. *c.* Seepage is dissimilar from streamflow and overbank flow because of the confined flow circumstance. Higher seepage flows occur in more porous material and are commonly enhanced by local precipitation and low stream stages. Piping is an example of sediment transport by seepage flows.
Wind	Exposed fine-grained cohesionless sediments are, to a small extent as far as streambank erosion is concerned, transported by wind.

Exhibit VII-3

STREAMBANK FAILURE MECHANISMS

Mechanism	Description
Surficial	Stresses within a streambank are changed by particular actions at the bank surface. Examples of surficial actions that affect bank stability are: *a.* Severe surface deterioration caused by mechanisms previously listed in Exhibit VII-1 may result in an unstable bank configuration. Erosion at the toe of the bank slope due to streamflow, erosion at the water surface due to waves, and erosion along the bank surface due to overbank and seepage flows are three common occurrences. *b.* Deep tension cracks due to excessive drying of a cohesive soil or similar structural change may cause the streambank to weaken and become unstable. Slaking may occur if excessive drying is followed by submergence. *c.* Overburden placed along top-of-bank may cause an otherwise stable streambank configuration to become unstable.
Moisture Variation	Stresses and the ability of the bank material to withstand stress without failing are both affected by moisture variation within the bank. Examples of these moisture-induced effects are: *a.* The slope of a cohesionless bank may be temporarily steeper than the angle of repose of the bank material due to capillarity or other nonpermanent stabilizing effect; when the nonpermanent effect is removed (usually by submergence and saturation of the bank material) the bank becomes unstable. *b.* During piping, cohesionless material is eroded from a location on the bank surface by seepage flow; a cavity develops and extends rapidly into the bank along a dominant seepage path. *c.* Liquefaction relates to fine-grained and loosely structured materials subject to a rapid increase in pore pressure (such as occurs during rapid drawdown or earthquake loading) and results in a large segment of bank material flowing downslope as a fluid-like mixture. *d.* During periods of high water table and low stream levels an added hydraulic loading is placed on the bank structure; this added load may directly cause failure unless relieved otherwise (say by seepage or piping). *e.* Swelling and shrinking during wetting and drying, respectively, affect the stability of clay soils. Substantial hydraulic pressures may result from water flowing freely into deep tension cracks (see Surficial, above) and into openings between different bank materials. *f.* The shear strength of clay soils is highly dependent on pore pressure (slow versus quick shear) and by degree of saturation.
Miscellaneous	Because of the nonhomogeneous (heterogeneous, interbedded, stratified, etc.) character of most streambanks, combinations of failure mechanisms are common; examples are: *a.* Artesian or gravity flow within a cohesionless or porous layer that evacuates sediment particles by piping can result in shear failures of layers higher in the bank. *b.* A thin clay layer that weakens and compresses during saturated bank conditions can also cause shear failures in the upper bank. *c.* Lubrication by water and high hydrostatic pressures along interfaces between bank materials that cause low resistance to sliding may result in a massive bank failure. *d.* Many other site-specific combinations of mechanisms occur.

PART VIII: DEMONSTRATION PROJECTS

The authorizing legislation for the Section 32 Program (see Exhibit III-1) specified: ". . . demonstration projects, including bank protection works;" and "Demonstration projects authorized by this section shall be undertaken on streams selected to reflect a variety of geographical and environmental conditions, including streams with naturally occurring erosion problems and streams with erosion caused or increased by man-made structures or activities." A number of particular sites or general locations for sites were specified along with the necessary agreements required of non-Federal interests. Demonstration projects were constructed at 68 locations nationwide (Exhibits III-2 and 3) and protect 125 miles of bank line. An additional 50 existing projects of varying nature and ages were observed at other locations nationwide (Exhibits XIII-1 and 5) and evaluated to supplement the demonstration project findings. PARTS IX to XIV of this Final Report describe the demonstration project aspects of the Section 32 Program from selection of sites and protection methods, through design, construction, and monitoring of the projects, to evaluation of observations and results to date. A listing of the types of protection and performance to date (summer 1981) at each demonstration and existing project and in the laboratory investigations is given in Exhibit VIII-1.

SELECTION OF SITES

The demonstration projects specified in the Section 32 Program legislation, the 1976 amendments, and the 1978-1980 appropriation bills were given first priority for construction. Additional projects were selected for their potential as field test sites for certain protective methods and materials. Other considerations in selecting sites for demonstration projects included (a) active erosion area representative of a general region, (b) effective demonstration, (c) results to be available within the program time frame, (d) environmental acceptability, (e) public interest, and (f) accessibility of area. Potential sites were selected and preliminary plans were prepared in coordination with local interests by Corps District offices and submitted through Corps Division offices to the Steering Committee for review. Steering Committee recommendations on site selection were submitted to the Office, Chief of Engineers, for approval. Preliminary plans for demonstration projects were approved by the Steering Committee and returned to Districts through Divisions for preparation of detailed construction plans and specifications.

SELECTION OF PROTECTION METHODS

The streambank protection techniques approved for testing in the field were to be generally capable of meeting the following criteria: (a) low construction and maintenance costs, (b) environmentally acceptable, (c) ability to withstand expected waves and flow velocities, (d) 500-to 1000-ft length for each different protection method, and (e) a minimum of three different protection methods at each site.

ENVIRONMENTAL CONSIDERATIONS

Most of the demonstration project sites covered only limited areas of the rivers and any environmental effects were very local. In general there were no adverse impacts anticipated. If there were, the Corps provided remedial action or did not use the site for a demonstration project. The Corps worked with concerned environmental interests, especially along the

Missouri River (see PART X), to obtain information for possible extrapolation to long reaches of protection. No significant environmental problems were encountered, and in some instances there were environmental benefits.

LOCAL SPONSORSHIP

Nearly all of the demonstration projects were located on non-Federal lands, and according to the authorizing legislation: "Prior to construction of any projects under this section, non-Federal interests shall agree that they will provide without cost to the United States land, easements, and rights-of-way necessary for construction and subsequent operation of the projects; hold and save the United States free from damages due to construction, operation, and maintenance of the projects; and operate and maintain the projects upon completion." All proposed construction was first coordinated with local authorities and private interests, and contractual agreements were reached before work began. The agreements included responsibilities for the projects after results of the demonstration program have been obtained. Some of the minimal types of bank protection methods being tested in the demonstration projects were expected to be damaged during the monitoring period. These were to be rehabilitated, as necessary, with funds budgeted under the Section 32 Program to provide adequate bank protection before the projects are transferred to the local sponsors. At some demonstration projects, construction activities have only recently been completed. Since the projects have not been tested thoroughly by a large range of flows, the evaluation period for determination of the structural and functional soundness of the individual demonstration projects is inadequate. There are no funds budgeted for the Section 32 Program after September 1982. All activities in the program will cease by then, except for minor monitoring of the demonstration projects on a limited basis in coordination with other Corps missions. All demonstration projects are being transferred promptly to the local sponsoring agencies (after joint inspections by the Corps and the sponsors). The transfers are being made regardless of the physical condition of the projects and whether or not they have been tested. Unsuccessful projects that are causing damage, which would not have been experienced without the project, will receive priority in the use of remaining funds.

PERFORMANCE MONITORING

Performance of the demonstration projects was monitored by the Corps field offices with guidance and suggestions from the Steering Committee. Plans for monitoring during the test period included observations and appropriate measurements of (a) the performance of the streambank protection method and materials, (b) any changes in the channel and bank-line configuration, (c) general streamflow and weather conditions, (d) flow and wave conditions adjacent to the protection works, (e) soils and foundation characteristics, and (f) aquatic and terrestrial habitats for fish and wildlife. A final report on each project or on groups of projects was prepared to formally record site, construction, and performance information. These reports are incorporated in Appendices D to G.

Monitoring guidelines for the demonstration projects were prepared early in the Section 32 Program to aid in providing uniform collection, documentation, and reporting of the data. The objective of the guidelines was a brief but thorough documentation of relevant aspects of the success or failure of the protection methods investigated. The types of data to be obtained were outlined in a sequential order and subdivided by physical characteristics. The sequential arrangement is a continuous process from historic through the present into the future, or from preconstruction through construction into the performance observation period. Physical data

were collected on: geometry; geology and soils; climate, hydrology, and hydraulics; streambank protection; and environment. Historic data (as available) were important in establishing expected rates of erosion for various combinations of bank material and streamflow conditions. Both natural and man-caused changing conditions (flow, stages, meanders, bank materials, etc.) that may have affected rates of erosion were investigated. Periodic visual inspections that included followup measurements of varying detail were used to document the performance of the protective works and relate the many interacting variables.

Exhibit VIII-1

STREAMBANK PROTECTION PERFORMANCE AT DEMONSTRATION AND EXISTING PROJECTS
AND IN LABORATORY INVESTIGATIONS - AS OF SUMMER 1981

TYPES OF PROTECTION				DEMONSTRATION OR EXISTING PROJECT	E1	E2	D68	E3	E4	E5	E6	E7	D38	D39	D40	D41	D42	D43	D44	D45	D46	D47	D48
				CE Division	Lower Mississippi Valley																		
				CE District	Memphis			New Orleans			Vicksburg												
				Map Number	E1	E2	D68	E3	E4	E5	E6	E7	D38	D39	D40	D41	D42	D43	D44	D45	D46	D47	D48
				Project Stream and Location	St. Francis River Clarks Corner, AR	Caney Creek Caney Creek, AR	White River Des Arc, AR	Red River Morameal, LA	Red River Fausse, LA	Red River Perot, LA	Big Creek Big Creek, LA	St. Catherine Creek Natchez, MS	Batupan Bogue Grenada Co., MS	Hunter Creek Tallahatchie Co., MS	Johnson Creek Panola Co., MS	N. F. Tillatoba Creek Tallahatchie Co., MS	Perry Creek Grenada Co., MS	S. F. Tillatoba Creek Tallahatchie Co., MS	Goodwin Creek Panola Co., MS	Hotophia Creek Panola Co., MS	Johnson Creek Panola Co., MS	N. F. Tillatoba Creek Tallahatchie Co., MS	Perry Creek Grenada Co., MS
				Calendar Year(s) Completed 19XX	64	75	80	75	75	70	76	73	77-9	77	81	76-8	78	72-8	78-80	80	81	77-9	78-9
Streambank Surface Protection	Upper and Middle Bank	Overbank Drainage Control																					
Streambank Surface Protection	Upper and Middle Bank	Low Porosity Cover		Surface Soil Stabilization		PA	PA																
				Anchored Membrane																			
				Filled Mats or Bags			F1						F2					F2					
				Ice																			
		Loose Material Cover (Porous)	Material	Stone Riprap	X		X	X1	X														
				Steel-Furnace Slag																			
				Rubble																			
				Soil-Cement Blocks				X2															
				Gravel																			
			Placement	Windrow																			
				Trench Fill			PA	PA1	PA														
				Surface Layer	PA			PA2	PA														
		Mfr'd Mtls		Concrete Blocks				PA															
				Filled Bags				PA															
		Porous Cover		Used Auto Tire Mats			PA					F1	F2					PA					
				Other Types (see Project)				PA															
		Bulkhead		(see Project)																			
		Vegetation		Grass		PA	PA						F2										
				Woody Shrubs																			
				Trees									F2										
				Anchored Trees																			
	Lower Bank and Toe	Low Por Cover		Surface Soil Stabilization		PA																	
				Filled Mats or Bags									F2					F2					
		Loose Material Cover (Porous)	Material	Stone Riprap																			
				Rubble																			
				Soil-Cement Blocks																			
				Gravel																			
			Placement	Composite Revetment																			
				Reinforced Revetment																			
				Windrow																			
				Trench Fill																			
				Surface Layer																			
		Mfr'd Mtls		Concrete Blocks																			
				Filled Bags or Tubes																			
		Porous Cover		Used Auto Tire Mats								F1	F2					PA					
				Gabion Mattress																			
				Other Types (see Project)	PA																		
		Bulkhead		Gabions																			
				Used Auto Tires																			
				Other Types (see Project)																			
		Vegetation		Grass/Trees		PA																	
				Anchored Trees																			
Stabilize or Modify Stream	Grade Control of Channel Bottom										F4								PA	PA		PA	PA
	Hold or Modify Channel Alignment	Longitudinal Controls		Stone Fill (incl Slag)									F2	PA	F1	F2	F2	PA					
				Filled Bags or Tubes																			
				Fence									PA										
				Open Frames (Jacks)																			
				Cribs													F2	FA					
				Used Auto Tires on Posts													F2						
		Protruding Controls		Hard Points																			
				Board, Wire, etc., Dikes						F4			PA					PA					
				Earth- or Gravel-Core Dikes																			
				Gabion Dikes																			
				Stone Dikes (incl Vanes)									PA	PA		F2		PA					
		Channel Relocation																					
Wave Reduction Breakwater																							

NOTE: CN - Project completed but not tested under design flow conditions; PA - Project performing as-designed; F1 - Partial failure, no repair/modification planned; F2 - Partial failure, repair/modification planned or under way; F3 - Partial failure, repair/modification completed but not tested under design flow conditions;

E8 E12 E13	E9	E10	E11	E14	E15	D58	E16 E18	E17	E19	E20	E21	E22	D16	D18	D17	D19	D20	D21	D22	D23	D24	D25	D26	D27	D28	D29	D30	D31	D32	D10
Kansas City							Missouri River – Omaha																							
Little Blue River Independence, MO	Republican River Milford Dam, KS	Little Timber Creek Frankfort, KS	Mud Creek Lawrence, KS	Big Blue River Nr. Marysville, KS	102 River Bedford, IA	Kansas River Eudora, Ks	Gering Drain Nr. Gering, NE	Plum Creek Nr. Denver, CO	Little Sioux River Onawa, IA	Deadman's Run & Antelope Creek, Lincoln, NE	Floyd River Sioux City, IA	West Fork Ditch Onawa, IA	Missouri River Hancock, ND	Missouri River Knife Point II, ND	Missouri River Knife Point I, ND	Missouri River Sandstone Bluff I, ND	Missouri River Sandstone Bluff II, ND	Missouri River Coal Lake Coulee, ND	Missouri River, Lewis & Clark 4-H Camp ND	Missouri River Wildwood, ND	Missouri River Sanger, ND	Missouri River Pretty Point, ND	Missouri River Price I, ND	Missouri River Price II, ND	Missouri River Horseshoe Butte, ND	Missouri River Eagle Park, ND	Missouri River Burnt Creek, ND	Missouri River I-94 Hwy, ND	Missouri River Fort Lincoln, ND	Missouri River Sunshine Bottom, NE
78	69	63	78	77	74	79	63-9	70	69	69-79	66	72	81	81	81	79	79	81	79	81	80	81	81	81	81	79	80	80	81	79
F2																														
					F2																									
	X																									X				
													X		X			X		X		X	X	X	X	X	X	X	X	X
	PA												CN		CN			CN		CN		CN	CN	CN	CN	PA	PA	PA	CN	PA
F2										PA			CN	CN	CN	PA	PA		PA	CN		CN	CN	CN			PA	PA		PA
					F2																									
X	X					X							X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X
																												X		
													CN		CN			CN		CN		CN	CN	CN	CN	PA	PA	PA	CN	PA
													CN	CN	CN	PA	PA	CN	PA	CN		CN	CN	CN	CN		PA	PA		PA
						PA								CN	CN	PA	PA	CN		CN		CN	CN		CN	F4	PA	PA		
PA	PA																													
									F2	PA																				
																										FA				
PA		F4	PA				PA			PA	F2	F4																		
				F1				PA																						
							PA																							
														CN		PA	PA		PA							F4	IA		CN	PA
																					CN						PA			
				PA				PA																						

F4 - Project performing as-designed with repair/modification in place; FA - Complete failure, project abandoned or another method has been used to stabilize bank; X - Type of material, corresponding to placement method indicated below.

Streambank Protection Performance (Continued)

DEMONSTRATION OR EXISTING PROJECT		CE Division	Missouri River (Continued)												New England						North Atlantic	
		CE District	Omaha (Continued)																		New York	Philadelphia
		Map Number	D34	D35	D12	D13	D36	D14	D15	D49	D50	D33	D11	D37	E23	E24	E25	E26	D55	D54	E27	D56
		Project Stream and Location	Missouri River Goat Island, SD	Missouri River Vermillion Boat Club, SD	Missouri River Brooky Bottom Road, NE	Missouri River Mulberry Bend, NE	Missouri River Vermillion R. Chute, SD	Missouri River Ryan Bend, NE	Missouri River Ionia Bend, NE	Yellowstone River River Road, MT	Yellowstone River Cheney Creek, ND	Missouri River White Swan, SD	Missouri River Cedar Co. Park, NE	Missouri River Elk Point I & II, SD	Connecticut River Hanover, NH	Connecticut River Thetford, VT	Connecticut River Turners Falls Pool, MA	Hayward Creek Quincy, MA	Connecticut River Northfield, MA	Connecticut River Haverhill, MA	Winooski River N. Williston, VT	Delaware River Paulsboro, NJ
TYPES OF PROTECTION		Calendar Year(s) Completed 19XX	79	78	78	80	78	78	78	80	80	81	80	80	62	72	77	77	81	79	36-40	80
Streambank Surface Protection — Upper and Middle Bank	Overbank Drainage Control																					
	Low Porosity Cover	Surface Soil Stabilization																				
		Anchored Membrane																				
		Filled Mats or Bags																				
		Ice																				
	Loose Material Cover (Porous) — Material	Stone Riprap						X														
		Steel-Furnace Slag																				
		Rubble																				
		Soil-Cement Blocks																				
		Gravel	X	X	X	X	X		X			X	X	X								
	Loose Material Cover (Porous) — Placement	Windrow																				
		Trench Fill																				
		Surface Layer	PA	PA	PA	PA	PA	PA	PA			CN	CN	CN								
	Mfr'd Mtls	Concrete Blocks												CN				PA				
		Filled Bags																				
	Porous Cover	Used Auto Tire Mats																				
		Other Types (see Project)																				
	Bulkhead	(see Project)																				
	Vegetation	Grass	PA				PA		PA		CN	CN	CN	CN			F2		CN	FA		
		Woody Shrubs									CN											
		Trees									CN											
		Anchored Trees																				
Streambank Surface Protection — Lower Bank and Toe	Low Por Cover	Surface Soil Stabilization																				
		Filled Mats or Bags																				
	Loose Material Cover (Porous) — Material	Stone Riprap	X	X	X	X	X	X	X		X	X	X	X	X		X				X	X
		Rubble																				
		Soil-Cement Blocks																				
		Gravel																				
	Loose Material Cover (Porous) — Placement	Composite Revetment	PA	PA	PA	PA	PA	PA	PA			CN	CN	CN								
		Reinforced Revetment	PA			PA	PA	PA	PA		CN	CN	CN	CN								
		Windrow	PA		PA		PA	F2	PA			CN	CN	CN								
		Trench Fill																				
		Surface Layer													PA		PA				PA	PA
	Mfr'd Mtls	Concrete Blocks																PA				
		Filled Bags or Tubes																		F1		
	Porous Cover	Used Auto Tire Mats																	CN	F1		
		Gabion Mattress																		EA		PA
		Other Types (see Project)																	CN	F1		
	Bulkhead	Gabions																				
		Used Auto Tires														PA			CN			PA
		Other Types (see Project)																				
	Vegetation	Grass/Trees															F2					
		Anchored Trees																				
Stabilize or Modify Stream	Grade Control of Channel Bottom																					
Hold or Modify Channel Alignment	Longitudinal Controls	Stone Fill (incl Slag)																				
		Filled Bags or Tubes																				F1
		Fence																				
		Open Frames (Jacks)																				
		Cribs																			FA	
		Used Auto Tires on Posts																				
	Protruding Controls	Hard Points	PA	PA	PA		PA		PA			CN	CN	CN								
		Board, Wire, etc., Dikes																				
		Earth- or Gravel-Core Dikes								CN												
		Gabion Dikes																				
		Stone Dikes (incl Vanes)				PA																
	Channel Relocation																					
Wave Reduction Breakwater																						

NOTE: CN - Project completed but not tested under design flow conditions; PA - Project performing as-designed; F1 - Partial failure, no repair/modification planned; F2 - Partial failure, repair/modification planned or under way; F3 - Partial failure, repair/modification completed but not tested under design flow conditions;

Streambank Protection Performance (Continued)

North Central								North Pacific			Ohio River																			
Detroit	Rock Island				St. Paul			Alaska	Seattle		Huntington						Louisville						Pittsburgh							
E28	E29	E30	E31	D60	E32	E33	D62	E34	E35	D57	E36	D4	D5	D6	D7	D59	E37	E38	E39	D8	D9	D61	E40	E41	E42	E43	D1	D2	D3	D53
St. Marys River Mission Point, MI	Illinois Waterway Banner Levee, IL	Bureau Creek Bureau Co., IL	Iowa River Louisa Co., IA	Iowa River Wapello, IA	Minnesota River Savage, MN	Minnesota River Mankato, MN	Lower Chippewa River Eau Claire, WI	Tanana River Fairbanks, AK	Fisher River Libby, MT	Green River Kent, WA	Hocking River Athens, OH	Ohio River St. Marys, WV	Ohio River Ravenswood, WV	Ohio River South Point, OH	Ohio River Portsmouth, OH	Kanawha River S. Charleston, WV	Ohio River Cloverport, KY	Ohio River Newburgh, IN	White River Edwardsport, IN	Ohio River Moscow, OH	Ohio River Mt. Vernon, IN	Little Miami River Milford, OH	Monongahela River Nr. California, PA	Ohio River Wheeling, WV	Ohio River Tiltonsville, OH	Woodcock Creek Saegertown, PA	Ohio R (Grave Cr) Moundsville, WV	Ohio River Moundsville, WV	Ohio River Powhatan Pt., OH	Allegheny River Wattersonville, PA
74	76	74	76	78	66	71-79	81	77-8	68	81	71	81	77	81	77	80	73	76	75	80	77	79	77	71	68	73	78	77	79	80
											PA																			
																PA														
																PA					F3FA									
								FA																						
						X	X						X		X	X	X	X		X	X			X						X
															X												X	X	X	
														X	X															
													X												X					
																														PA
						PA	PA						PA	PA	F4	PA	PA	PA		PA	PA			F4	PA		PA	PA	PA	PA
							PA																							
							PA																							
												CN		F2		PA													PA	
							F1	F1		F3											PA									
																											F2		PA	
											PA				F4	PA				F1							F1	F1	PA	
																											F1	F1	PA	
																PA														
							PA	F1																						
				PA																										
X	X				X	X	X		X	X	X						X	X				X								
											X																			
																						PA								
PA	PA				F1	PA	PA		PA	PA	PA						PA	PA				PA								
							PA																							
							PA																							
							F1 PA	F1																						
													F1									PA								
												CN											PA							
																						PA								
								F1																						
									F1																					
																													PA	PA
													F4																	
							F1 PA						F2																	
		F1		F4																										
							PA																							F2
			FA	F4																										
																										F2				
												CN																		
																			PA											
																F2														

F4 - Project performing as-designed with repair/modification in place; FA - Complete failure, project abandoned or another method has been used to stabilize bank; X - Type of material, corresponding to placement method indicated below.

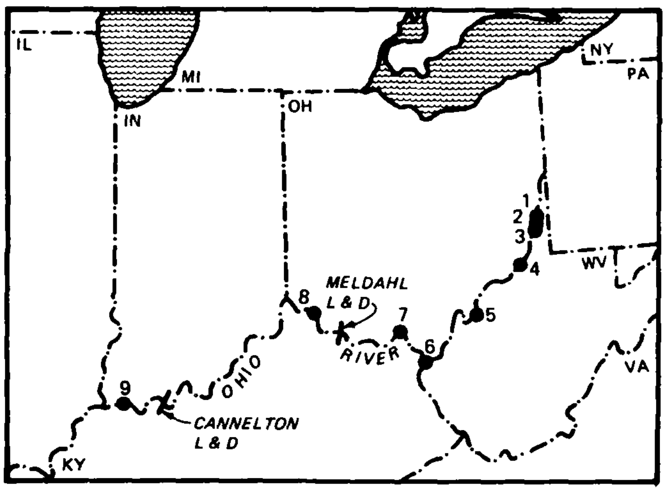
Streambank Protection Performance (Continued)

DEMONSTRATION OR EXISTING PROJECT		CE Division	South Atlantic			South Pacific				Southwestern							Waterways Experiment Station		TOTAL	Waterways Experiment Station	
		CE District	Mobile	Wilmington		Los Angeles	Sacramento	San Francisco		Albuquerque			Galveston	Little Rock		Tulsa					
		Map Number	D63	E44	D65	E45	D66	D51	D52	E46	E47	D64	E48	E49	D67	E50	L-BB	L-DO	--	L-H	L-G
		Project Stream and Location	Pearl River, Monticello, MS	Little Rockfish Creek, Hope Mills, NC	Roanoke River, Leesville, VA	Mill Creek, Mill Creek Levee, CA	Sacramento River, Ordbend, CA	Eel River, Fernbridge, CA	Van Duzen River, Carlotta, CA	Rio Grande, Espanola, NM	Cuchillo Negro Creek, Truth or Conseq., NM	Rio Chama, Abiquiu, NM	Trinity River, Moss Hill, TX	Arkansas River, Merrisach Lake, AR	White River, Jacksonport, AR	Arkansas River, Ellinwood, KS	Big Black River, Nr. Vicksburg, MS	Durden Creek, Vicksburg, MS	TOTAL INSTALLATIONS IN FIELD	Hydraulics Laboratory Investigations	Geotechnical Laboratory Investigations
TYPES OF PROTECTION		Calendar Year(s) Completed 19XX	80	76	81	67	81	79	78	51	77	81	66	72	80	74	79	79	--	81	81
Overbank Drainage Control																			1		
Streambank Surface Protection – Upper and Middle Bank	Low Porosity Cover	Surface Soil Stabilization													F3				5		PA
		Anchored Membrane															F3	PA	2		F1
		Filled Mats or Bags															F4	F4	9		
		Ice																	1		
	Loose Material Cover (Porous) – Material	Stone Riprap										X			X		X	X	22	X	
		Steel-Furnace Slag																	4		
		Rubble	X																3		
		Soil-Cement Blocks																	1		
		Gravel																	24		
	Loose Material Cover (Porous) – Placement	Windrow			CN														2		
		Trench Fill																	3		
		Surface Layer	PA									CN			PA		PA	PA	48	F2	
	Mfr'd Mtls	Concrete Blocks	PA																5		
		Filled Bags																	[illegible]		
	Porous Cover	Used Auto Tire Mats	PA		CN														10		
		Other Types (see Project)																	5		PA
	Bulkhead	(see Project)																	2		
	Vegetation	Grass		F4	CN		CN								PA		PA		40		PA
		Woody Shrubs					CN										CN		6		
		Trees					CN												4		
		Anchored Trees																	2		
Streambank Surface Protection – Lower Bank and Toe	Low Por Cover	Surface Soil Stabilization																	1		
		Filled Mats or Bags																F4	5		
	Loose Material Cover (Porous) – Material	Stone Riprap	X		X		X	X				X			X			X	53	X	
		Rubble	X																1		
		Soil-Cement Blocks																	1		
		Gravel																	1		
	Loose Material Cover (Porous) – Placement	Composite Revetment																	23		
		Reinforced Revetment																	24	PA	
		Windrow																	21	PA	
		Trench Fill						PA							PA				3	PA	
		Surface Layer	PA		CN		CN	F4				CN						PA	23	PA F2	
	Mfr'd Mtls	Concrete Blocks																	2	FA	
		Filled Bags or Tubes																	2		
	Porous Cover	Used Auto Tire Mats			CN														6		
		Gabion Mattress		F4							PA								6		
		Other Types (see Project)																	6	F? PA	F1
	Bulkhead	Gabions																	2		
		Used Auto Tires																	5		
		Other Types (see Project)										CN		F4					3		
	Vegetation	Grass/Trees			CN					PA									4		
		Anchored Trees							PA										3		
Stabilize or Modify Stream	Grade Control of Channel Bottom																		13	PA	
Hold or Modify Channel Alignment	Longitudinal Controls	Stone Fill (incl Slag)																	8		
		Filled Bags or Tubes																	2		
		Fence						F4	PA										8	PA FA	
		Open Frames (Jacks)								F4						CN			4		
		Cribs																	4		
		Used Auto Tires on Posts																	1		
	Protruding Controls	Hard Points					CN	PA											20	PA F1	
		Board, Wire, etc., Dikes											F2						6		
		Earth- or Gravel-Core Dikes																	3		
		Gabion Dikes				F4					PA	CN							4		
		Stone Dikes (incl Vanes)																	8	PA	
	Channel Relocation																		1		
Wave Reduction Breakwater																			1		

NOTE: CN - Project completed but not tested under design flow conditions; PA - Project performing as-designed; F1 - Partial failure, no repair/modification planned; F2 - Partial failure, repair/modification planned or under way; F3 - Partial failure, repair/modification completed but not tested under design flow conditions; F4 - Project performing as-designed with repair/modification in place; FA - Complete failure, project abandoned or another method has been used to stabilize bank; X - Type of material, corresponding to placement method indicated below.

PART IX: OHIO RIVER DEMONSTRATION PROJECTS

The Corps Districts in the Ohio River Division investigated numerous sites on the Ohio River and tributaries where active streambank erosion was occurring. Exhibit IX-1 shows the locations of the demonstration projects and Exhibit IX-2 presents some pertinent data on each of them. A detailed report on these projects is given in Appendix D. Two Ohio River tributary demonstration projects at Milford, Ohio, on the Little Miami River and at South Charleston, West Virginia, on the Kanawha River are reported in Appendix G with the Demonstration Projects on Other Streams, Nationwide, along with the project at Wattersonville, Pennsylvania, on the Allegheny River.



1. Moundsville (Grave Creek), WV
2. Moundsville, WV
3. Powhatan Point, OH
4. St. Marys, WV
5. Ravenswood, WV
6. South Point, OH
7. Portsmouth, OH
8. Moscow, OH
9. Mt. Vernon, IN

Exhibit IX-1. Locations of Ohio River demonstration projects

Exhibit IX-2

SUMMARY OF OHIO RIVER DEMONSTRATION PROJECTS

Map No.	Location and River Mile	CE Office	Erosion Causative Agents	Protective Methods Tested	Project Length ft	Total Project Costs $1000	Completion Date
1	Moundsville (Grove Creek) West Virginia 102.0	Pittsburgh Pennsylvania	Piping; sloughing on falling stage	Graded, steel-furnace slag (5 sections) Automobile tire wall (gravel-filled) Upper bank shrubs (7 kinds) Upper bank legumes and grasses (5 combinations)	1850	199	Jun 78
2	Moundsville West Virginia 106.5	Pittsburgh Pennsylanvia		Graded, steel-furnace slag (7 sections) All vegetation (shrubs, 8 kinds) Upper bank shrubs (8 kinds) Upper bank legumes and grasses (14 combinations)	2130	160	May 77
3	Powhatan Point Ohio 109.8	Pittsburgh Pennsylvania		Graded, steel-furnace slag (5 sections) Automobile tire wall and mat (gravel-filled) Upper bank shrubs (1 kind)	2000	176	Feb 79
4	St. Marys West Virginia 154.9	Huntington West Virginia		Automobile tire mats Dumped-stone dikes Automobile tire wall (concrete-filled)	1200	397	Dec 80
5	Ravenswood West Virginia 220.5	Huntington West Virginia		Wood breakwater fence (4 designs) Stacked gabions (firebrick-filled) Quarry-run rock fill Longard tube Upper bank grasses and willows (3 combinations)	1400	206	Aug 77
6	South Point Ohio 316.7	Huntington West Virginia		Concrete waste and rock spoil Automobile tire mat on sand fill Automobile tire mat on graded bank Concrete waste buttress	1300	281	Jan 81
7	Portsmouth Ohio 355.1	Huntington West Virginia		Waste rock blanket Quarry-run rock steps Quarry-run rock fill Steel-furnace slag fill Upper bank grasses and willows (3 combinations)	1600	251	Jan 77
8	Moscow Ohio 442.5	Louisville Kentucky	High-stage streamflow through relatively straight reach	Riprap toe protection Grass seeding (4 methods)	1300	352	Jan 81
9	Mt. Vernon Indiana 829.0	Louisville Kentucky	Wave action; high-stage streamflow against concave bank of bendway; sloughing on falling stage	Wire mats over crushed stone Fabriform with riprap toe Bagged sand-cement with riprap toe	750	108	Feb 77

CHANNEL CHARACTERISTICS AND EROSION PROBLEMS

Summary and Range of Streambank (Geotechnical) Characteristics

The Ohio River Valley exhibits three different types of terrains. In the upper portion of the valley, the alluvial soils on top of the rock forming the riverbank are predominantly glacial outwash, gravel, sandy gravel, and gravelly sand. Although erosion problems do exist in the upper portion of the valley, they are less extensive than those in the middle or lower reaches, because riverbank soils are relatively more erosion-resistant. Also, streambank protection is provided in many places because of extensive industrial developments. The central portion of the valley has more alluvial fill than in the upper reaches, as a result of extensive flood deposits. Typically, riverbank soils consist of erodible silty clays underlain by glacial outwash sands and gravels. A characteristic feature of the banks is the presence of layered soils with interbedded channels or seams of highly erodible fine sands or sandy silts.

The lower portion of the Ohio River Valley is characterized by wide, flat floodplains, low banks consisting of fine-grained silty soils. These soils are also erosive; however, erosion usually occurs in undeveloped or agricultural lands.

Summary and Range of Flow (Hydraulic) Characteristics

The Ohio River main stem, formed by the confluence of the Allegheny and Monongahela Rivers at Pittsburgh, Pennsylvania, is 981 miles long. The area of the watershed is 19,500 square miles at the beginning of the Ohio River; it increases to 203,900 square miles at its confluence with the Mississippi River. Precipitation varies greatly over the basin, with an average annual value of 45 in. The Ohio River flood season is from December to April with major floods generally occurring between January and March. The following are mean annual flows at various stations based on an average of 40 years of record.

Station	River Mile	Mean Annual Discharge (1,000 cfs)
Pittsburgh, Pennsylvania	0	32.2
Huntington, West Virginia	310	77.5
Cincinnati, Ohio	470	98.3
Evansville, Indiana	792	134.5

Average stream velocities attain a maximum value of 6 to 7 fps during flood periods, low-flow average stream velocities are in the range of 1 to 2 fps.

Causes of Erosion and Failures

In 1977 the Ohio River Division conducted exhaustive engineering studies on causes of bank instability in connection with a litigation claiming that bank erosion was caused by the construction of high-lift locks and dams. The study area was limited to the Cannelton and Meldahl pools of the Ohio River (see Exhibit IX-1 for location of dams), but the results can generally be extrapolated to other reaches of the river main stem. Mechanisms causing erosion and failure include:

(1) Current-velocity-related tractive forces.
(2) Rapid drawdown and stage fluctuations triggering slumpages.
(3) Removal of bank soil by seepage of water through zones of low erosion resistance (piping) with slabbing and caving of overlying soils.
(4) Weather-induced spalling of upper bank surface soils.
(5) Wind and boat waves reworking and removing failed bank soils.

The primary mechanisms along the Ohio River appear to be (2) and (3), as described above, which most often occur in upper bank alluvium during flood recession periods. It was found by field monitoring that wind- or towboat-generated waves are of minor importance, except in special locations such as in lock approach, mooring, and fleeting areas. The causes described above are those acting in the vicinity of riverbanks and do not include areas affected by landslides of colluvial soil resulting from geological factors. Typical bank erosion problem sites along the Ohio River are illustrated in Exhibit IX-3.

Left bank near Moundsville, West Virginia (View toward upstream, March 1977)

Right bank near South Point, Ohio (View toward upstream, January 1977)

Right bank near Moscow, Ohio (View toward downstream, June 1981)

Exhibit IX-3. Typical streambank erosion problems along the Ohio River

Significant Special Problems

In the northern portion of the basin, rivers are frozen over for a substantial time period during the winter. The breakup of winter ice exerts forces on protective works that must be considered in the design. In the rest of the basin, ice formation is a problem only during unusually severe winters.

TYPES OF PROTECTION INSTALLED AT THE OHIO RIVER DEMONSTRATION PROJECTS

General Descriptions

Briet, general descriptions of the protective structures and materials used under the Section 32 Program in the Ohio River Division are given below:

Quarry-run rock protection consists of durable, graded-stone material with maximum size limited to 12 to 18 in. (100 to 300 lb) and containing a specified maximum amount of fine material. It was placed either in a layer of specified thickness or as a stone-filled wedge on eroded portions of the bank. The top elevation of the protection varied between 3.0 to 10.0 ft above normal pool level. (Normal pool is the minimum river level maintained for navigation throughout the year.) A filter layer was generally used between the protection and the natural bank material.

Concrete-waste and rock-spoil protection consists of rubble available from demolition of concrete buildings, mixed with quarry spoil. It was placed to various elevations above normal pool level. The protective layer was underlain by synthetic filter fabric.

Steel-furnace slag protection is a locally available and inexpensive waste product of steel manufacturing. It was placed either in layers of various specified thicknesses, or as a wedge to replace eroded bank material. Top elevation of the protection was 3 to 5 ft above normal pool level. The furnace slag is of higher specific gravity than quarry-run stone; therefore, top sizes could be smaller to provide comparable protection.

Transverse stone dikes are stone structures protruding from the bank as "hard points" approximately perpendicular to the direction of the flow. They provide indirect protection by diverting potentially erosive currents from the bank.

Used automobile tires were installed to provide protection in the form of either a wall (bulkhead) built to elevations ranging from 4 to 6 ft above normal pool level, or of a mattress placed on the bank, which was previously graded to a stable slope. In the tire wall construction, the tires were filled with sand and capped with concrete; and the area between the wall and the bank was backfilled with sand and gravel. The tire mattress had tires chained together and anchored to the underlying soil. Exhibit IX-4 illustrates the tire wall.

Gabion protection consisted of wire cages filled with small stone or waste brick material. They were generally constructed to 3 ft above normal pool elevation and filter material was placed between the gabions and the original bank.

Breakwaters are structures whose primary purpose is to protect the banks from any erosion that may be caused by wave action. They are designed to absorb all or a portion of the energy generated by the waves. The type constructed was a wooden fence parallel to the bank, extending to 3 ft above normal pool.

Fabriform mats consist of a fabric envelope filled with pumpable sand and cement grout. This mat was placed from the normal pool elevation to the top of the bank. A bedding layer was provided under the mat. Exhibit IX-5 shows this type of protection.

Longard tube protection is a fabric tube placed parallel to the direction of the flow and filled with either sand and gravel or concrete. Various sizes are available; a tube diameter of 3.3 ft was used on one project.

Crushed stone and wire mat protection consisted of crushed stone (4-in. maximum diameter) protected by a weir mat anchored to the underlying soil. The top of protection extended to 10 ft above normal pool elevation. See Exhibit IX-6 for a view of this method.

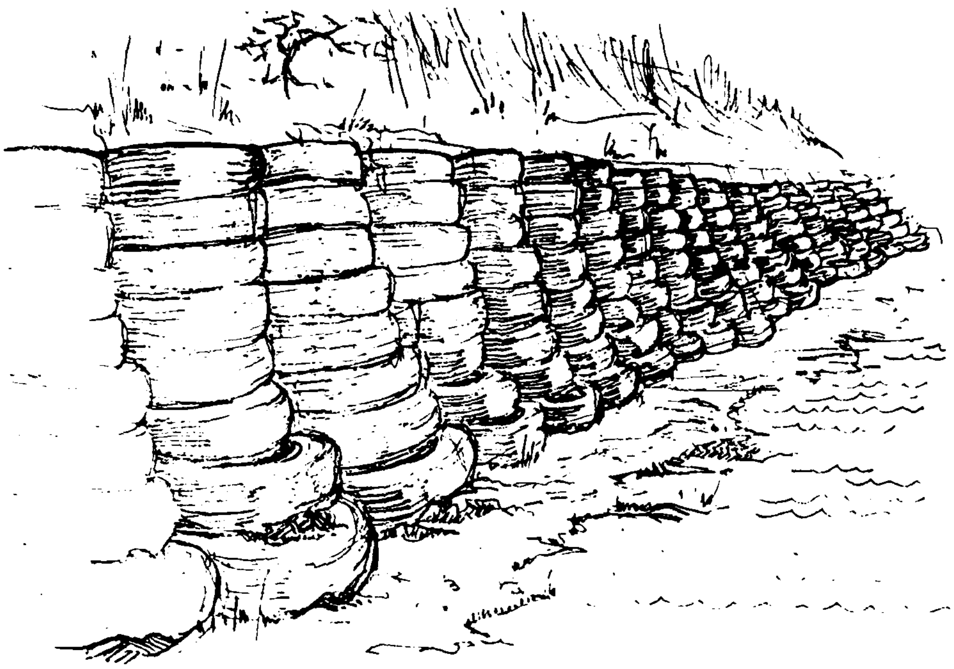


Exhibit IX-4. Used tire wall (bulkhead) built at the Moundsville, West Virginia (Grave Creek), demonstration project

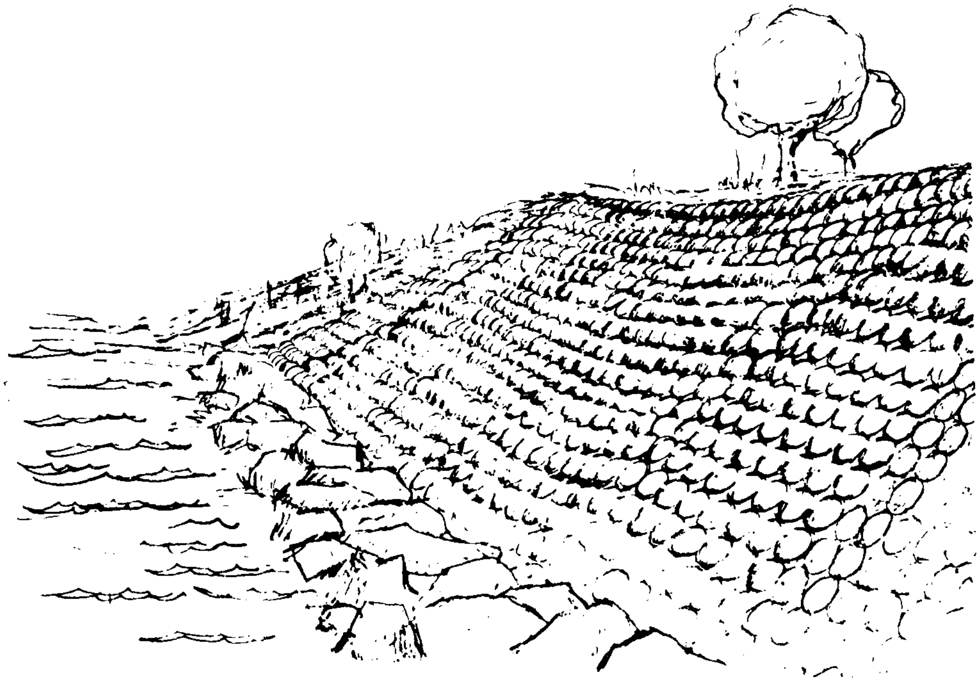


Exhibit IX-5. Fabriform mat protection of the streambank at the Mt. Vernon, Indiana, demonstration project

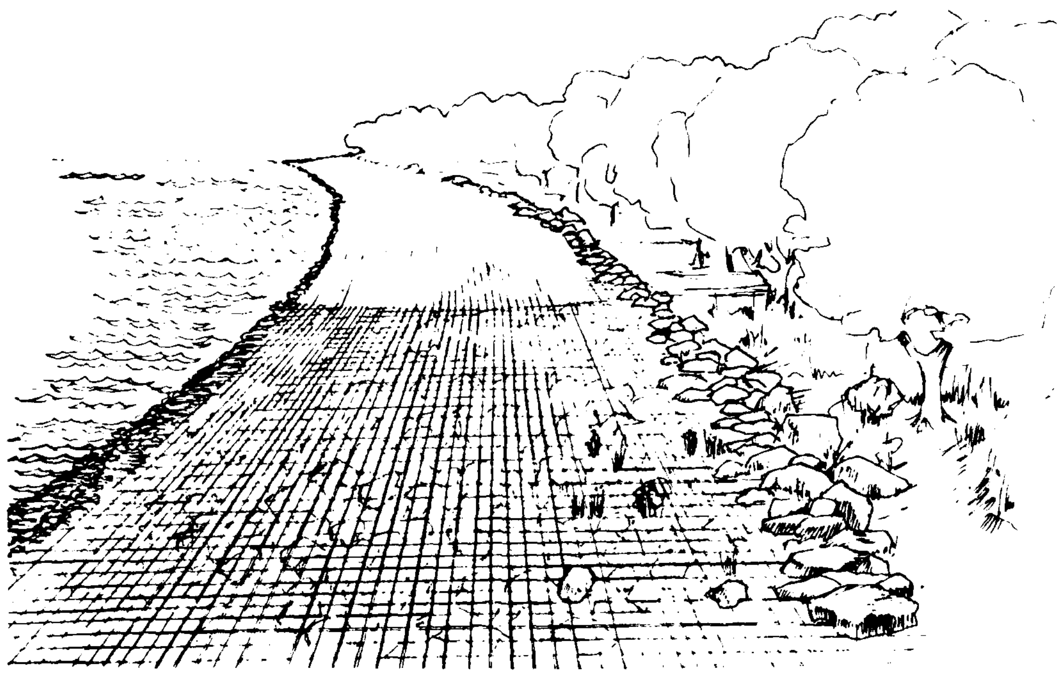


Exhibit IX-6. Crushed stone with wire mat cover on streambank at the Mt. Vernon, Indiana. demonstration project

Vegetative protection, consisting of either grass or shrubbery, was provided in conjunction with some of the methods described previously. The area above the elevation of the top of the various schemes was protected in this manner after the bank had been previously graded to a stable slope. An experimental scheme consisting only of vegetation failed shortly after construction.

Grout-filled paper bags consisted of nylon reinforced paper bags filled with sand and cement grout and placed individually on a prepared slope. The protection was provided from normal pool elevation to the top of the bank.

The Corps Districts attained compliance with the National Environmental Policy Act (NEPA) through the environmental assessment of the effects of constructing the Section 32 Demonstration Sites. Additionally, the actions were evaluated according to the Sec 404(b)(1) guidelines for the disposal of dredged or fill material into waters of the United States, and were thus found to be in compliance with Sec 404 of the Clean Water Act.

Relative Costs

The following tabulation shows average costs (1981 level)* for the main protective structures and methods employed in the Ohio River demonstration projects. The costs cover construction (material, equipment, and labor), and include engineering and design plus supervision and administration. The detailed costs are included in the project reports

* The following annual average cost factors based on the ENR Index were used to adjust costs from the year of construction to 1981: 1976-2401, 1977-2577, 1978-2776, 1979-3003, 1980-3237, and 1981-estimated 3450.

(Appendix D). Unit costs include grading of bank where applicable; however, they exclude planting of vegetation. See the last entry listed for vegetation costs.

Protective Structure or Method	Average Cost per Linear Foot of Bank Line Protected (1981 $)
Quarry-run rock	140-230
Concrete waste rubble	125-150
Steel-furnace slag	80-115
Transverse stone dike	80-130
Automobile tire wall	150-200
Automobile tire mat	275-360
Gabion protection	235-300
Breakwater fence	150
Fabriform	260
Grout-filled paper bags	165
Longard tube (diameter 3.3 ft)	205
Crushed stone and wire mat	115
Vegetation - shrubs	25-30
grass	8-10

MONITORING AND OBSERVATIONS OF DEMONSTRATION PROJECTS

In general, monitoring at each demonstration project included visual reconnaissance, photography, and evaluation of project performance. Velocity measurements were taken at some projects in the vicinity of the bank at intermittent discharges. At some sites, piezometers were installed and groundwater levels were monitored for comparison with simultaneous river levels. Stage hydrographs are available for all projects and they are included with the detailed project reports in Appendix D. Time and financial constraints did not permit all the instrumentation and monitoring originally considered in the demonstration program. When the shorter period for monitoring activities became apparent, monitoring efforts were scaled down accordingly. However, observations at the demonstration projects will continue on an unscheduled basis in connection with the normal missions of the Corps of Engineers. Although the projects, in general, performed adequately during several flood seasons, no major floods occurred during this period. Extremely high floods, especially when followed by rapid fall of river levels, may introduce a more critical combination of destabilizing factors than those already experienced at the projects.

MAINTENANCE AND REHABILITATION OF DEMONSTRATION PROJECTS

A purely vegetative scheme that had failed after flood conditions has been rehabilitated with a combination structural-vegetal scheme and has performed adequately since restoration. Some piping-related problems on the upper bank were corrected by regrading the slopes and placing additional rock underlain by filter fabric. A portion of a scheme utilizing grout-filled paper bags failed due to sliding because they were placed directly over a rather steep slope. This damage has been repaired with quarry-run stone and has since performed adequately. On some projects, piping-related bank instability is noticeable on the upper portion of the banks. Some

projects, piping-related bank instability is noticeable on the upper portion of the banks. Some protection methods experienced damage due to vandalism. As mentioned previously, some demonstration projects have not yet experienced the most critical conditions that would affect their performance. These conditions would be associated with unusually high floods and or extremely rapid changes in river levels. Rehabilitation work to control piping-related problems may be required, either by extension of the protective scheme to the upper bank or the design of protective methods specifically developed for this condition.

SUMMARY OF FINDINGS

At the implementation of the Section 32 Program in the Ohio River Division, the design of protective schemes was based mainly on concepts of the bank erosion causative mechanisms that had been recognized at that time, which did not include piping action in the upper bank. Accordingly, design concepts emphasized the provision of protection on a level at or slightly above normal pool elevation, considering principally the erosive forces introduced by the action of the current and/or waves. Within this concept, a great variety of protective materials were employed with emphasis on local availability, economy, and simple constructibility. Another new design concept was to provide protection to a limited zone above normal pool as an economical alternative to conventional methods which carry protection to the top of the bank.

Significant Observations

- Minor loss of bank material due to piping was observed in the upper bank at several sites after flood periods.
- Minor ice damage was observed on transverse dikes after spring breakup of a frozen river. The damage was not sufficient to impair the stability of the protection.
- Tire wall protections were subject to vandalism in some instances.
- The Longard tube protection also experienced vandalism and had to be repaired.
- The grout-filled paper bag protection placed on a relatively steep slope experienced a partial failure due to sliding. The bags were also subject to ice damage.
- Structures placed in the river, such as wave fences, were damaged by tows.

Conclusions

- The studies performed in 1977 in connection with the previously mentioned litigation disclosed the presence of additional bank-instability-causing mechanisms, such as piping and mass slumpage acting mainly in the upper bank horizons. These mechanisms are related to river drawdown and groundwater seepage, and they also depend on the composition of the bank material. The performance of the projects must be evaluated in light of these additional mechanisms that did not become apparent until after implementation of the majority of the program. Although the projects were not designed specifically against drawdown-related mechanisms, it is evident that some of the measures taken, such as flattening the existing slope, placement of filter fabric, or bedding material, were substantially helpful in this respect. The generally satisfactory performance of the major project components to date supports this statement. Some areas of bank instability along the Ohio River and its tributaries result from colluvial landslides; however, projects constructed under this program were not designed to effect stabilization of slope failures.

- Protections placed in the proximity of normal pool elevation were found to be adequate to stabilize the toe of the banks against current-related tractive forces. However, in many instances erosive mechanisms acting on the upper bank following high river stages (piping) caused loss of bank material above the adequately protected lower level.
- On navigable rivers, light protective structures placed in the river, such as fences, etc., are subject to damage from tow traffic.
- Vandalism is a serious problem and should be considered to the extent possible in the design of protective works. This could be a problem for otherwise technically effective methods.
- Used automobile tire walls were found to be an effective method of protection except for occasional vandalism problems. Tire mats were effective except when placed on steep (1 on 2 or greater) slopes. In the latter case, problems developed due to instability of granular backfill or sliding of the entire mat.
- Steel-furnace slag was a very effective and economical protection method, although some environmental concern exists due to leachates from the slag.
- Control of overbank drainage is essential to prevent damage of protective works due to washouts of underlying natural or filter materials.
- The following plants were found to provide effective vegetation cover in the Ohio River area:

Purple osier willow	(*Salix purpurea*)
Red osier dogwood	(*Cornus siricea*)
Crown vetch	(*Coronilla varia*)
Tall fescue	(*Festuca arundinacea*)
Reed canary grass	(*Phalaris arundinacea*)

Recommendations

- All-vegetation schemes are not recommended on the Ohio River main stem.
- If vegetation is used in conjunction with other methods, planting should not be attempted after late fall.
- The effectiveness of additional protective methods designed specifically for piping should be investigated.
- Geotechnical problems associated with a specific site must not be overlooked, and an adequate design is needed to maintain slope stability under all conditions anticipated.

SIGNIFICANT PARTICIPATION BY OTHER ORGANIZATIONS

Local sponsors of the Ohio River demonstration projects listed in Exhibit IX-2 are, respectively: City of Moundsville, West Virginia; the Northern Pan Handle Soil Conservation District, West Virginia; the Board of Park Commissioners of the Powhatan Point Municipal Park District, Belmont County, Ohio; City of St. Marys, West Virginia; City of Ravenswood, West Virginia; Village of South Point, Ohio; City of Portsmouth, Ohio; Village of Moscow, Ohio; and the City of Mount Vernon, Indiana. Some guidance was received from the Soil Conservation Service for selection of the vegetative cover to be used. Local industries furnished waste material (concrete, firebricks, and slag) used for some types of protection investigated.

PART X: MISSOURI RIVER DEMONSTRATION PROJECTS

Twenty-eight demonstration projects were constructed under Work Unit 6 along three reaches of the Upper Missouri River. Seventeen of these projects are located downstream from Garrison Dam in North Dakota, two downstream from Fort Randall Dam in Nebraska and South Dakota, and nine downstream from Gavins Point Dam along the Nebraska and South Dakota border. All of the 17 projects in North Dakota were at sites specifically authorized by Congress, whereas the remaining reaches included sites selected by the Steering Committee. Priority was placed on providing protection at locations where erosion rates were highest. Fund limitations resulted in some of the projects being scaled down from the original proposals. See Exhibit X-1 for locations of the completed projects. Exhibit X-7 presents brief summaries of the Missouri River demonstration projects. A detailed report on these projects is given in Appendix E.

IN NEBRASKA

10. Sunshine Bottom
11. Cedar County Park (2 parts)
12. Brooky Bottom Road
13. Mulberry Bend
14. Ryan Bend
15. Ionia Bend

IN NORTH DAKOTA

16. Hancock
17. Knife Point I
18. Knife Point II
19. Sandstone Bluff I
20. Sandstone Bluff II
21. Coal Lake Coulee
22. Lewis and Clark 4-H Camp
23. Wildwood
24. Sanger
25. Pretty Point
26. Price I
27. Price II
28. Horseshoe Butte
29. Eagle Park
30. Burnt Creek
31. I-94 Highway
32. Ft. Lincoln

IN SOUTH DAKOTA

33. White Swan
34. Goat Island
35. Vermillion Boat Club
36. Vermillion River Chute
37. Elk Point (2 parts)

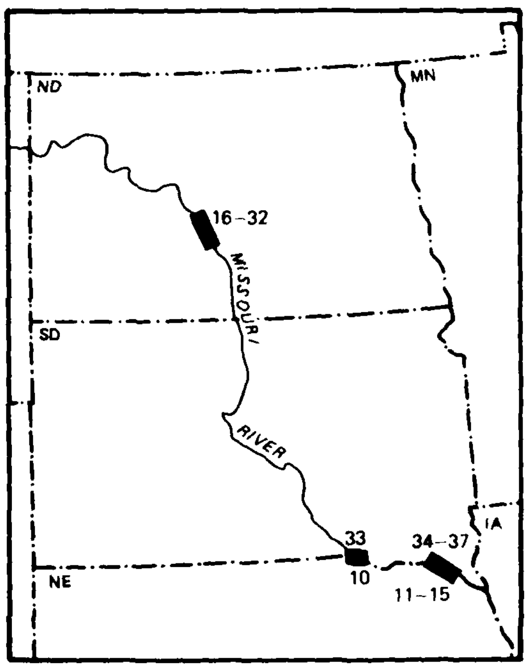


Exhibit X-1. Locations of Missouri River demonstration projects

CHANNEL CHARACTERISTICS AND EROSION PROBLEMS

Summary and Range of Streambank (Geotechnical) and Flow (Hydraulic) Characteristics

Exhibit X-2 summarizes the average or most dominant range of geotechnical and hydraulic characteristics encountered at the various demonstration project sites constructed by the Omaha District in the three Missouri River reaches: Garrison Dam to Lake Oahe, North Dakota; Fort Randall Dam to Niobrara, Nebraska and South Dakota, and Gavins Point Dam to Ponca, Nebraska and South Dakota.

Causes of Erosion and Failures

The predominant factors influencing erosion conditions on the Missouri River reaches downstream from Garrison Dam in North Dakota and Fort Randall Dam in South Dakota are channel meander, varied streamflow, channel restrictions, and wave attack, listed in the estimated order of impact magnitude. In the 80-mile reach downstream from Garrison Dam, normal daily power-generation fluctuations result in river stage differences of 7 ft near the dam diminishing to 1 ft at Bismarck, North Dakota. For the 36-mile reach downstream from Fort Randall Dam, river stage differences, resulting from power-generation fluctuations, near the dam range from maximums of 8 ft (December-March) and 4 to 5 ft (April-November) to differences of 2 ft and 1 ft for corresponding periods at the Verdel, Nebraska, gage, located 33.5 miles downstream.

Predominant factors influencing erosion in the 65-mile reach downstream from Gavins Point Dam, which essentially has long-duration steady-state discharge releases, are all classes of hydraulic erosion and wave erosion. Divided flow conditions, channel meander, sand-wave sediment transport, and winter ice jams all contribute to flow impingement directed toward unprotected erodible bank lines.

Other general causes along the Missouri River reaches are bank-line undercutting (erosion at the base of slope), high sand content soil characteristics, saturated banks, and frequent freeze-thaw cycles during the winter period.

TYPES OF PROTECTION INSTALLED AT THE MISSOURI RIVER DEMONSTRATION PROJECTS

General Descriptions

Sketches of the typical bank protection schemes demonstrated along the Missouri River are shown in Exhibits X-3, X-4, and X-5.

Windrow revetment consists of a mound of stone placed on the ground, or partially or totally buried, immediately adjacent and parallel to the general alignment of the eroding bank. As bank-line caving reaches the windrow, the stone is undercut, thereby falling down the bank and protecting the bank against further erosion. (See Exhibit X-5.)

Reinforced revetment has a bank-line toe of erosion-resistant material placed riverward of the high bank, reinforced intermittently by stone-filled tiebacks extending landward from the toe into the riverbank. (See Exhibit X-4.)

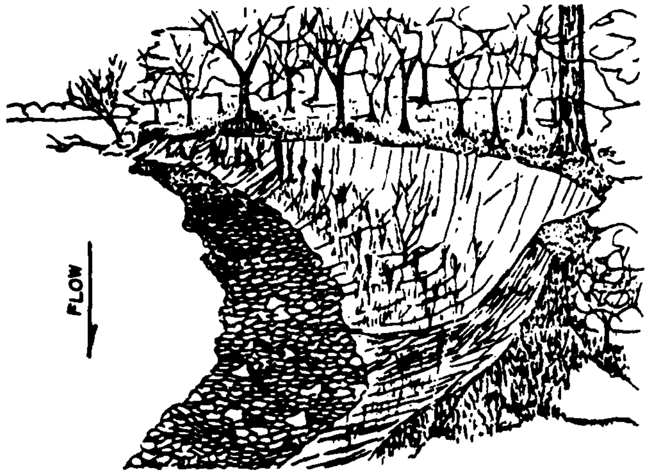
Composite revetment has a bank-line toe of erosion-resistant material, an upper bank treatment covering the zone of normal seasonal fluctuations, and a freeboard zone that is generally vegetated. (See Exhibit X-3.)

Exhibit X-2

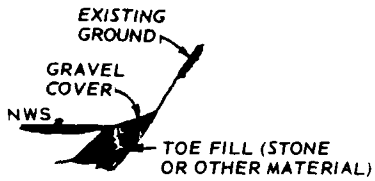
MISSOURI RIVER DEMONSTRATION PROJECTS

SUMMARY AND RANGE OF GEOTECHNICAL AND HYDRAULIC CHARACTERISTICS

Characteristics	Garrison Dam to Lake Oahe	Fort Randall Dam to Niobrara	Gavins Point Dam to Ponca
Soil Classifications (Unified)	ML, SM, SP, CH	ML, SP, MH	ML, SM, CH
Sieve analysis	90-100% passing #80	85-100% passing #80	75-100% passing #80
Surface permeability	0.01 to 1.5 in./hr	0.10 to 2.0 in./hr	0.06 to 2.0 in./hr
Tributary streams	Knife River, Heart River	Choteau Creek	James River, Vermillion River
Geological formations	Glacial till overlying sedimentary marine deposits	Colluvium and alluvium overlying sedimentary marine deposits	Colluvium and alluvium overlying sedimenary marine deposits
Average channel depth (thalweg)	4 to 20 ft	6 to 20 ft	5 to 25 ft
Width between high banks	1,200 to 5,000 ft	1,000 to 7,500 ft	600 t0 5,500 ft
Primary channel width	400 to 2,400 ft	400 to 3,600 ft	400 to 4,200 ft
Slope	0.45 to 0.85 ft/mile	0.35 to 0.6 ft/mile	0.6 to 1.5 ft/mile
Average daily discharge	25,800 cfs	34,200 cfs	35,800 cfs
Average annual suspended-sediment load	Bismarck - 7,621,000 tons/year	Niobrara - 1,927,000 tons/year	Sioux City - 10,920,000 tons/year
Composition of suspended sediment	29% silt and clay, 71% sand	30% silt and clay, 70% sand	32% silt and clay, 68% sand
Size of bed material	Varies from coarse- to fine-grained sediments	Varies from coarse- to fine-grained sediments	Varies from coarse- to fine-grained sediments
Site bed material sediment, median size (D_{50})	Varies from 0.7 to 0.25 mm	Varies from 1.3 to 0.25 mm	Varies from 2.0 to 0.35 mm
Velocities (within 75 ft of bank line along project sites)	0 to 4.5 fps	0 to 4.2 fps	0 to 6.6 fps



COMPOSITE REVETMENT



TYPICAL SECTION

Exhibit X-3. Typical bank protection schemes, composite revetment

Hard points consist of two components: a short spur of erosion-resistant material extending from the bank riverward, and a root of stone placed in a trench excavated landward from the bank line. (See Exhibit X-5.)

Earth core dikes are mounds of sand fill extending riverward of the bank line and protected on the upstream face by a stone toe and covered by a thin layer of stone. (See Exhibit X-4.)

Refusals consist of erosion-resistant material placed in a trench excavated landward at the upstream end of each revetment segment to prevent flanking.

Tree retard systems generally consist of groups of trees cabled together, placed perpendicular to the bank line, and anchored in place using cables with fabricated weights. A small stone root is constructed into the bank line to anchor the landward end of the tree and protect the landward end of each retard from flanking by overtopping flows.

Vane dikes are low-elevation, within-the-channel fills of stone or lower grade material that hold the high-velocity erosive flows away from the banks and encourage the accumulation of sediment on the landward side. The flow is allowed to course both ends and overtop the structure to create and preserve environmentally desirable shallow, braided channels.

Relative Costs

Demonstration project construction costs for each structure type by reach, including engineering and design, supervision and administration, and rehabilitation costs are compared in Exhibit X-6.

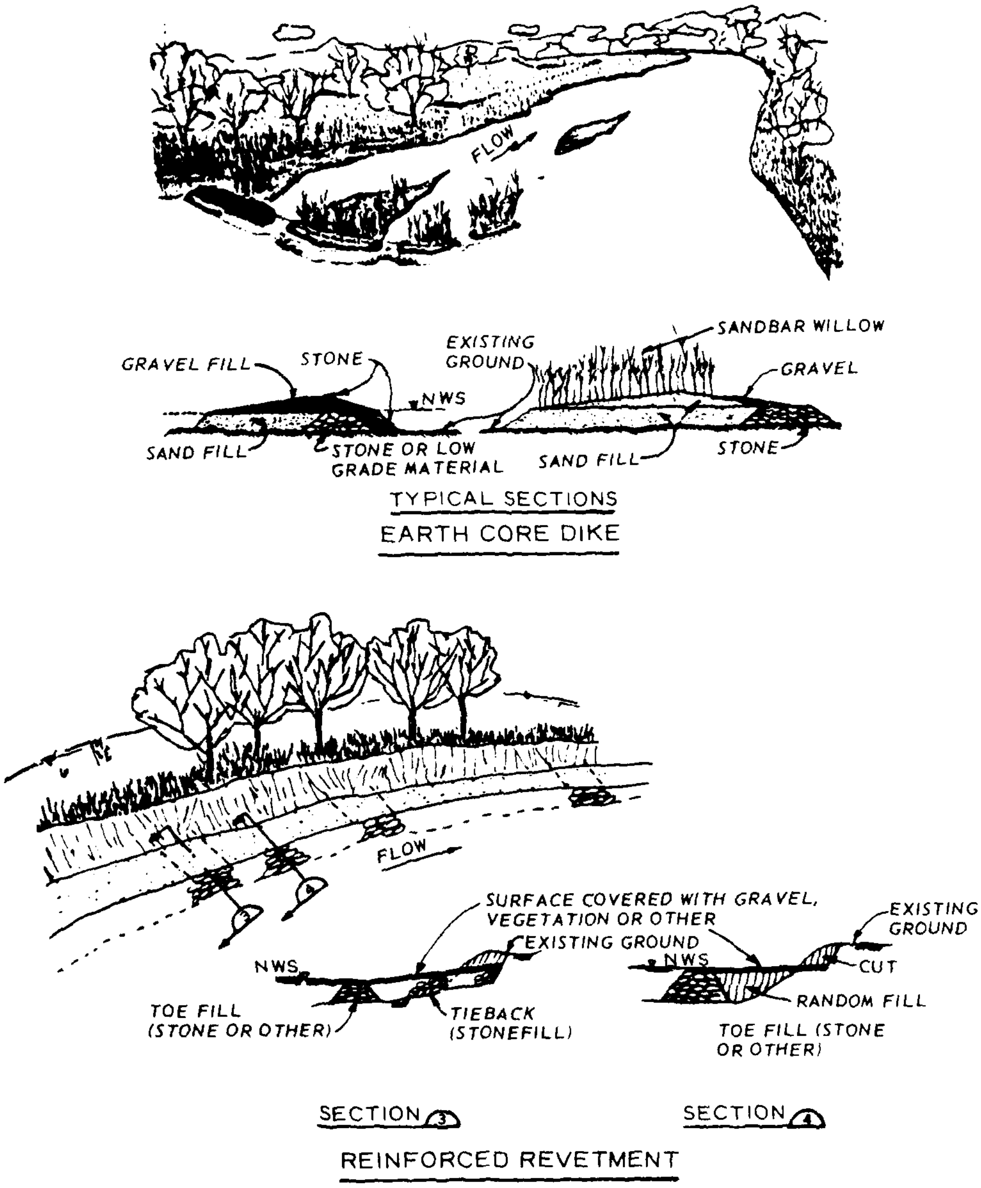
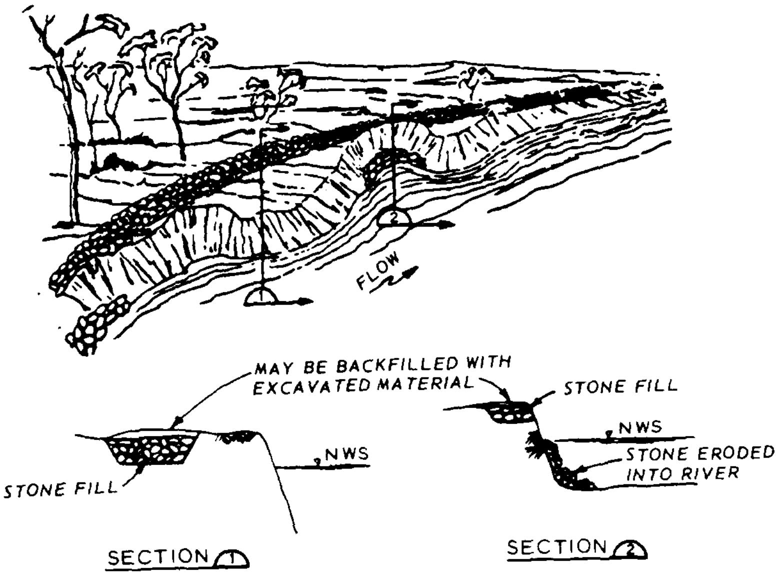
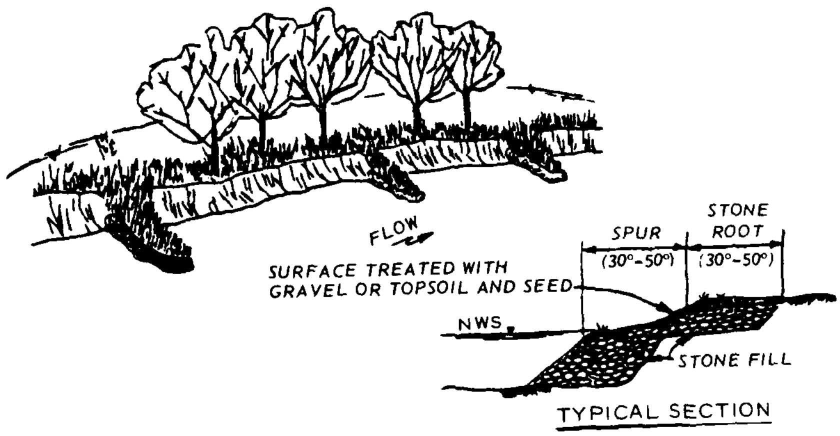


Exhibit X-4. Typical bank protection schemes, reinforced revetment



WINDROW REVETMENT



HARD POINT SYSTEM

Exhibit X-5. Typical bank protection schemes, windrow revetment

Exhibit X-6

MISSOURI RIVER DEMONSTRATION PROJECTS

Range of Construction Costs (in 1981 $), Including Engineering and Design, Supervision and Administration, and Rehabilitation

Structure Type	Garrison Dam to Lake Oahe ($)		Fort Randall Dam to Niobrara ($)		Gavins Point Dam to Ponca ($)	
	Cost/LF	Cost/Foot of Bank Line Protected	Cost/LF	Cost/Foot of Bank Line Protected	Cost/LF	Cost/Foot of Bank Line Protected
Windrow revetment	Max 162 Min 87 Avg 103	Max 162 Min 87 Avg 103	--	--	Max 135 Min 52 Avg 84	Max 135 Min 52 Avg 84
Reinforced revetment	Max 182 Min 92 Avg 125	Max 182 Min 92 Avg 125	Max 135 Min 130 Avg 133	Max 135 Min 130 Avg 133	Max 138 Min 57 Avg 92	Max 138 Min 57 Avg 92
Composite revetment	Max 153 Min 82 Avg 110	Max 153 Min 82 Avg 110	Max 112 Min 112 Avg 112	Max 112 Min 112 Avg 112	Max 138* Min 41 Avg 81	Max 138* Min 41 Avg 81
Hard points	Max 213 Min 85 Avg 143	Max 85 Min 34 Avg 57	Max 173 Min 147 Avg 158	Max 69 Min 59 Avg 63	Max 159 Min 45 Avg 107	Max 64 Min 9 Avg 43
Earth core dike	Max 216 Min 168 Avg 188	Max 72 Min 42 Avg 63	--	--	--	--
Refusal	Max 208 Min 87 Avg 131	--	Max 180 Min 119 Avg 149	--	Max 135 Min 52 Avg 98	--
Tree retards	Max 47 Min 47 Avg 47	Max 24 Min 24 Avg 24	--	--	--	--

* Includes rehabilitation.

MONITORING AND OBSERVATIONS OF DEMONSTRATION PROJECTS

Historic erosion rates and general preconstruction bank-line configurations were evaluated using controlled aerial photography at a scale of 1 in. = 2000 ft. Bank-line and hydrographic surveys obtained for preparation of construction plans and specifications provided initial information on preconstruction site conditions. A "Monitoring and Documentation" section was incorporated into each construction contract that required detailed measurements and photographs before, during, and after the construction of specific erosion control structures. Follow-up field data were obtained on a continuing basis at project sites as determined necessary by periodic visual site inspections. Details on data obtained at each site are discussed in Appendix E for the Missouri River demonstration projects. Future monitoring measurements and observations will extend through September 1982 at a few locations. Subsequent evaluations will be conducted in conjunction with other project activities in the local areas where demonstration projects were constructed. Future detailed field data will be obtained for evaluation of specific erosion control structure types where significant structural alterations are noted or following large prolonged streamflow discharge occurrences (e.g. streambank streambed cross sections, ground level aerial photography, flow velocity measurements, and construction material analysis when appropriate). Details on structure effectiveness at each site are discussed in Appendix E.

MAINTENANCE AND REHABILITATION OF DEMONSTRATION PROJECTS

Structure rehabilitation was originally scheduled to be accomplished only prior to transfer of maintenance responsibility to the local sponsor. However, at a few locations rehabilitation could not be delayed until the end of the program, because such a delay would have resulted in the deterioration of adjacent structure components of the erosion control system, possibly rendering a large portion of the erosion control works ineffective. Projects requiring early rehabilitation were the Eagle Park Area in North Dakota, Vermillion River Chute Area in South Dakota, and Mulberry Bend Area and Brooky Bottom Road Area, both in Nebraska. Details of the rehabilitation measures are discussed in Appendix E. Additional projects requiring rehabilitation in FY 1981 included the Sandstone Bluff Area in North Dakota, Ryan Bend Area in Nebraska, Ionia Bend Area in Nebraska, and the Vermillion River Chute Area in South Dakota. All projects will continue to be observed and repaired as necessary prior to transferring them to the local sponsor, subject to the availability of funds.

SUMMARY OF FINDINGS

Windrow Revetment

General Advantages. Windrow revetment can effectively eliminate erosion along a wide variety of bank shapes and channel conditions. Construction procedures are relatively simple; specialized heavy equipment is not required and excessive construction time is not necessary. After adequate coverage of the protected slope has been provided, excess stone may be salvaged from the windrow and used elsewhere. Hazardous bank-line erosion sites can be protected without risking the safety of personnel during construction. Windrow revetment structures do not alter the general flow regime of the river. When the buried technique is used, the stone material should be covered with a minimum of 2 ft of soil material, and the reestablishment of volunteer vegetation ground cover is very rapid. Reasonably well-graded material performs adequately and is less expensive than a specified gradation.

General Disadvantages. Minor additional bank-line erosion loss must occur to allow the stone material to displace to the underwater bank area and function as designed. Land construction equipment requires a minimum clearing of 50 ft on the overbank to permit adequate structure placement, and if funding restricts future ability to salvage unused material, some material may remain on top of the high bank. When minimum material rates are used, subsequent periodic monitoring is necessary to determine adequacy of design during functional operation of the bank protection. If the stone supply in the initial windrow is not adequate, additional stone can be added as required.

Significant Observations. Smaller gradation (200-lb maximum weight with median size of 7 to 8 in.) stone is more effective in windrow revetments than a large gradation (500-lb top size with median size of 9 to 10 in.) stone because the smaller gradation stone forms a more dense, closely chinked protective blanket layer that is necessary to resist erosion of the underwater bank slope. Windrow material placement configurations using a combination of low-grade material (specific gravity not less than 1.70) and stone material (specific gravity not less than 2.35) are not appropriate for bank heights exceeding 6 ft above normal water surface because the low-grade material, when displaced to the upper bank slope, is subjected to excessive freeze-thaw cycles, causing material breakdown. Also, the condition applies to lower banks where the bank-line erosion is consistent but slow, resulting in delayed displacement of material to the underwater slope area. The bank height is not a critical design consideration. An estimate of the maximum bed scour along the toe of the structure is critical in determining the amount of material necessary. The stone can either be placed on the top of the bank or buried in a trench or bank-line notch and still function adequately. The buried trench windrow revetment offers a natural appearance after vegetation is reestablished on the soil cover. Construction progress is impaired by wet ground conditions during both floating plant and land-based construction. Construction by floating plant using the bank-line notch techniques reduces upper bank disturbance during construction. However, windrow revetments can be constructed by land-based methods using conventional construction equipment and at reduced construction costs.

Recommendations. Medium to small-sized, reasonably well-graded stone is recommended. Windrow revetment should be used primarily in cleared upper bank areas or locations requiring only minimal construction clearing. The material application rate should be determined by the channel depth, bank height, and material size and by estimating the expected maximum bed scour along the future structure alignment. Land-based construction equipment is desirable and the most cost-effective. Windrow revetment can be constructed during cold temperatures when the stream is frozen. Construction of a 50- to 75-ft windrow refusal composed of stone extending landward into the bank is mandatory at the upstream end of each revetment segment to eliminate the possibility of the erosion flanking the structures.

Reinforced Revetment

General Advantages. Reinforced revetment can be used effectively for erosion control along varying channel and bank-line conditions and is very efficient in eliminating future losses in severely eroding areas. This type of revetment can be constructed by either land-based or floating-plant equipment. Land-based construction is the generally accepted method except where the riverbanks are excessively high and unstable; in which case, floating-plant construction is the most economical and desirable. Since the toe of the bank-line structure is relatively low and the tiebacks are buried and covered, the structure is less visible.

General Disadvantages. Construction of the tiebacks and the toe placement may be difficult in areas characterized by high, steep, unstable banks. Prolonged periods of high flows will result in some upper bank erosion until a high level bench is established. When the revetment toe crown elevation is constructed to a design which is less than normal water surface, the structure presents a near-bank hazard to small boats.

Significant Observations. The elevation of the toe can range from slightly below to 2 ft above normal water surface depending upon the frequency and duration of high flow fluctuations. The stone tieback spacings vary depending on the maximum toe elevation, the alignment of the bank line, and the rate of bank-line erosion. Low-grade material (e.g., low-grade chalk with a specific gravity between 1.9 and 2.3) was found to be effective in the lower toe zones of the structure (which are not affected by frequent freeze-thaw and wet-dry cycles). No upper bank treatment is required with the exception of the tieback structure. Gravel cover over the stone toe provides an accepted cosmetic treatment; however, it does not improve the erosion control characteristics other than enhancing vegetative growth. Excavation for the toe-fill is required when very shallow water depths exist along the toe-fill alignment in order to provide for proper placement at the necessary material application rate which is determined for estimated maximum bed scour. The excavated material should be placed between the toe material and the bank line. When local bank-line conditions have a relatively shallow underwater bench, this formation can be utilized to reduce the toe material requirement in stabilizing the underwater bank zone.

Recommendations. Reinforced revetment can be used along actively eroding banks where immediate preservation of the upper bank area is desired, and provides erosion control on a wide variety of bank-line configurations and alignments. The maximum toe elevation should be constructed to or above the normal water-surface elevation. Low-grade stone material should only be used in the lower underwater toe zones of the structure. Tiebacks should be spaced at 100 ft center-to-center along straight or concave-shaped banks where erosion is severe and spaced at a minimum of 150 ft center-to-center along convex-shaped banks where the flow streamlines are parallel to the bank line. Use gravel cover over the stone toe only when aesthetics are a desirable project objective. The unprotected bank-line areas between structure segments should not exceed 300 ft where the flow is parallel to the bank and should not exceed 200 ft where the flow streamlines approach an angle of 45 deg or more to the bank line. The minimum length of a single revetment segment should be 400 ft. A 50- to 75-ft windrow refusal consisting of stone extending landward into the bank should be placed at the upstream end of each segment of revetment to eliminate the possibility of erosion flanking the revetment segment. Construction by floating plant is recommended, if possible, to eliminate the need for haul roads and upper bank clearing. Barge loading and staging areas used for floating-plant construction should be located as near the construction site as possible to reduce construction costs. When bank conditions are favorable, reinforced revetment can also be easily constructed using land-based equipment procedures.

Composite Revetment

General Advantages. Composite revetment construction requires minimal upper bank disturbance; however, the design can include a wide range of upper bank erosion control treatments. Generally, composite revetment is the most economical of all revetment types demonstrated on the Missouri River to construct and maintain, and it is an effective erosion control structure for many different bank-line and channel conditions. This type of revetment is easily constructed with land-based or floating plant equipment and procedures; however, where the streambank is excessively high and unstable, floating plant construction is desirable. Locally available construction materials can be incorporated into the structure design of the upper bank treatment.

General Disadvantages. Full bank protection requires upper bank clearing and this zone is very visible at normal flows. Very deep scour holes along the eroding bank line can require large quantities of stone material to establish the revetment toe section.

Significant Observations. Frequent high-stage fluctuations require upper bank protection such as graded upper bank covered with cellular concrete blocks, gravel, clay, cobbles and

spalls, filter fabric, or any combination thereof. Gravel cover over the stone toe improves the aesthetics, but adds little in the way of erosion control. The gravel does, however, permit easier access to the stream for wildlife and enhances vegetation growth. Excavation for the toe-fill is required when shallow water depths exist along the toe-fill alignment in order to provide proper placement at the necessary material application rate for estimated maximum scour. Lower (below water surface) toe zones can effectively function with low-grade material (e.g., soil-cement, low-grade chalk with specific gravity between 1.9 and 2.3) because this zone is not affected by frequent freeze-thaw and wet-dry cycles. Low-grade material in the upper bank zones deteriorates in only a few years. The riverward slope of the toe should be constructed to the natural angle of repose of the toe material. Of the various upper bank treatments tested, all have functioned effectively to protect the upper bank zone but the cellular concrete blocks are the most expensive and potentially vulnerable to protection failure due to displacement. Desirable maximum lengths for revetment and unprotected segments are based on river hydraulic conditions. Close interstructure spacing will reduce the scallop size in the unprotected segment, while maintaining the advantage of lower costs than for complete bank-line revetment. When applying this technique to other rivers, the bank-line erosion rate along with the anticipated riverbed scour should be used as a guide to determine the structure increment lengths.

Recommendations. Composite revetment should be utilized along actively eroding banks where immediate preservation of the upper bank area is desired and additional bank-line erosion losses (i.e., windrow revetment) are not acceptable. Construction with floating plant is recommended, if possible, to reduce the environmental impact on the upper bank during construction by eliminating the need for haul roads and upper bank clearing. Use of floating-plant construction procedures requires that the location of the barge loading staging area be as near the construction site as possible to reduce total construction costs. The material application rate must be based on the projected anticipated scour depth along the structure alignment. Along shallow channel areas, excavation for the toe-fill is necessary for adequate toe placement of required material quantity. The maximum composite stone toe height should be limited to approximately 2 ft above normal water-surface elevation. A 50- to 75-ft windrow refusal composed of stone extending landward into the bank is mandatory at the upstream end of each revetment segment to eliminate the possibility of erosion flanking the revetment segment. The minimum length of a single revetment segment should be 400 ft. The unprotected bank-line areas between structure segments should not exceed 300 ft where the flow is parallel to the bank and should not exceed 200 ft where the flow streamlines approach the bank at an angle of 45 deg or more to the bank line.

Hard Points

General Advantages. Hard points have only limited environmental impact on upper bank vegetation, because only minor timber clearing is required for construction access and stone root placement. Hard points have a minimal cost per linear foot of bank line protected. This type of erosion control system develops and maintains maximum diversity in the aquatic and near riverbank environment. Structures are simple in cross-section design and therefore easy to construct. Structure crown surface can be modified to also function as a boat launching facility.

General Disadvantages. Hard-point systems allow limited temporary erosion to continue until equilibrium is reached in the unprotected bank-line spaces between hard-point structures. Hard points can create turbulence eddies at the structure's riverward end which may temporarily increase erosion rates along the near downstream bank-line area when structure length is very short.

Significant Observations. The stone spur and stone root portion of each hard point is mandatory for structure effectiveness. Hard points are most effective along relatively long,

straight or slightly convex-shaped bank-line configurations. The gravel cover over the hard-point spur crown area is a cosmetic treatment and does not provide added erosion control. The principle of allowing limited temporary erosion in the unprotected areas between individual hard points is an integral feature of the project design. The presence of the stone roots excavated 30 to 50 ft into the bank, along with the structure spacing, limits the amount of scalloped erosion along the unprotected bank-line segments and protects the structure from being flanked. Hard points have experienced some degradation along the upstream side of the spur and root during high-flow periods and spring ice breakup.

Recommendations. Hard points are most effective along straight or slightly convex-shaped bank lines where the stream flow lines are parallel to the bank line. The unprotected areas between individual hard points may be varied depending on the length of the structure spur and root, the alignment shape of the bank line, and the severity of the present erosion conditions. The recommended minimum length of each hard point is 100 ft (50-ft spur and 50-ft root) with an unprotected spacing between structures of approximately 250 ft. This general recommended layout relates to approximately 5 ft of bank line protected from extensive erosion for each foot of hard-point length that extends riverward of the water's edge. When developing the structure system layout, the bank-line alignment, shape, and direction of stream flow lines are critical spacing considerations.

Hard-point construction should be limited to areas where channel depths are no greater than 10 ft within 50 ft of the bank line to avoid large stone material quantity requirements. The crown elevation of the hard-point spur should be at or near the normal water surface at the riverward end and a minimum of 5 ft above normal water surface at the landward location. The entire hard-point structure should be aligned 10 to 20 deg in the downstream direction from the normal to the bank line at time of construction. The lower toe zone below normal water surface of the spur should be constructed using a large-sized gradation of stone or low-grade material (500-lb maximum size) and the remaining portions of the hard point should be constructed using a medium-sized stone gradation (200-lb maximum size).

Earth Core Dikes

General Advantages. Earth core dikes require only minimal amounts of clearing along the high bank for construction equipment movement. Due to alignment location, earth core dikes protect a downstream bank-line length several times the length of the structure and are therefore cost-effective. The structure surface can easily be revegetated and made to blend into the natural surroundings. The construction of a short low-elevation section in the structure allows a limited amount of water to flow behind the structure during normal or high flows to improve the riverine environment behind the structure. This creates a large, river-connected, slack backwater area that has been identified by fish and wildlife interests as the most critical and scarce type of riverine aquatic habitat along the Missouri River. In these backwater areas, the water warms up faster and submerged aquatics have a chance to become established.

General Disadvantages. Earth core dikes have the possibility of inducing sediment deposition downstream from the structures. The structures, which sometimes extend riverward up to approximately 2,000 ft, can have a major impact on the flow area. Construction of this type of structure is difficult and requires a larger concentration of construction equipment than other bank protection structural methods. A relatively large borrow area must be available near the construction site to provide sufficient material for the embankment fill portion of the structure. The earth core dike structure is an appropriate erosion control structure for only the larger rivers, such as the Missouri.

Significant Observations. A notch is essential in the design of an earth core dike if a slack backwater area downstream of the structure is a planned environmental objective. Construction of the earth core dike will not require clearing of the upper bank-line area, except where access

to the river must be established for construction. The cost of earth core dikes per linear foot is greater than other erosion control structures; however, the overall cost per linear foot of bank-line erosion control is very cost-effective compared with other techniques demonstrated in the Missouri River Division. Ice and high flows do not alter the effectiveness of the structure.

Recommendations. Earth core dikes should only be constructed along areas where existing sandbars can be incorporated into the structure alignment in order to reduce the amount of embankment necessary. The size, location, and layout of the structure must not restrict the channel or have a significant effect on the prevailing river regime. Avoid structure alignments that would redirect the main flow to the opposite bank and increase erosion at bank-line locations downstream. The construction of a functional low-elevation notch is an important part of the earth core dike design if improvement in riverine habitat is desired. A vegetation planting program is recommended for the above-normal water-surface area of the structure to improve the natural cover and structure appearance. The landward end of the dike should have a vehicle traffic barricade (i.e. fence or large boulders) to restrict public vehicular access over the dike crown after construction.

Tree Retards

General Advantages. Tree retards are inexpensive to construct. The necessary trees were locally available from required cleared areas. Trees placed perpendicular to the bank tend to cause minor flow diversion and induce bar formation. High flows and wave wash over the top of the trees will tend to naturally form a beach back to the high bank. The trees also provide excellent fish habitat, and the created bars provide good fishing sites.

General Disadvantages. Higher flows overtop the trees and can continue to erode the unprotected banks. Large trees are required to form an effective retard. This type of structure is very vulnerable to destruction by ice flows.

Significant Observations. Flow fluctuations, ice, and beavers destroy the tree elements. Tree retards have a short functional life span and if near bank-line bars do not develop shortly after placement, the retards can become ineffective. The largest, locally available trees should be used in fabricating the retard element.

Recommendations. Tree retards are not recommended as an erosion control method unless they are constructed in areas not subjected to severe ice flows. When smaller trees are used, a greater number are required to fabricate the retard. A significant number of the tree limbs should extend above normal water surface.

SIGNIFICANT PARTICIPATION BY OTHER ORGANIZATIONS

Federal

U. S. Fish and Wildlife Service (F&WS), USDA Forest Service, USDA Soil Conservation Service; U. S. Bureau of Reclamation, U. S. Environmental Protection Agency. The F&WS offices in Bismarck, North Dakota, and Pierre, South Dakota, provided separate interim reports on the environmental impacts of the Section 32 Program. These reports are included in Appendix E. The North Dakota Game and Fish Department concurred with the assessment made by the Bismarck Area Office of the F&WS of the demonstration projects on the Missouri River between Garrison Dam and Lake Oahe in North Dakota. The report prepared by the F&WS Area Office in Pierre, South Dakota, was coordinated with the South Dakota Department of Game, Fish, and Parks, and the Nebraska Game and Parks Commission. This report evaluated the Section 32 Program projects constructed on the Missouri River between Fort Randall and Ponca, Nebraska.

Several comments were expressed that are identical in both reports:

(1) During the construction phase, the use of floating plant is generally preferred to land-based construction methods. Construction by floating plant requires only minimal environmental disturbance of the upper bank area by eliminating the need for haul roads and upper bank clearing.

(2) One of the positive effects of the program is the substrate now provided by rock revetments and previously unavailable. The substrate is beneficial to macroinvertebrate production, spawning bed materials, and added habitat diversity.

(3) Procurement of woodland preservation easements to protect riparian habitat has also been advocated by both reports.

In the Garrison Dam to Oahe reach, the F&WS (North Dakota) report indicated the following.

(1) Adverse impacts on the aquatic ecosystem due to construction of erosion control structures have been minimal. One problem associated with the aquatic ecosystem was observed at the Sanger project area where an earth core dike was constructed. The backwater areas created behind such erosion control structures provide nursery areas for many fish species. However, the area downstream from the earth core dike could possibly silt in if sufficient flow does not pass through the low-elevation notch. If this occurs, many small pools could remain during low-flow periods and the fish could become stranded. Hopefully, this can be avoided by redesign of the notches, allowing adequate flow through the notch at low river stages, or maintenance of access to the river for the young-of-the-year fish.

(2) Concerns over wildlife impacts were identified because of the anticipated woodland clearing by landowners after a bank area is stabilized. This has not happened to any great degree. In fact, project construction itself has resulted in minimal habitat destruction. Generally, the number of trees lost in construction is too small to quantify; most of these trees would have been lost to erosion without the stabilization. It is the observation by the F&WS, North Dakota, that positive attempts have been made to keep the impacts of construction at a minimal level. Haul roads were routed around existing trees or where construction was necessary in a wooded area, the right-of-way was kept to a minimum. In most cases, the tree loss in the right-of-way would have occurred anyway because of the rapid erosion of the bank line.

(3) The North Dakota Game and Fish Department does not foresee any major environmental problems provided that project features, locations, methods, or theories of construction do not change and coordination continues.

(4) Overall, the Section 32 Program in North Dakota went very smoothly with only minor environmental effects observed in the seven completed sites constructed through 1980.

(5) The Section 32 Program has been unique in that there has been excellent coordination and cooperation between the Corps of Engineers and the F&WS. In several instances, project specifications were designed to minimize environmental damage. Any problems that were foreseen with regard to wildlife habitat or bald eagles were brought to the attention of the Corps Omaha District or site inspectors. A meeting or onsite review was immediately called, and any problems or delays were alleviated. While this required that extra time be spent on preproject reviews, onsite meetings, inspections of construction activities, etc., it resulted in virtually no habitat losses.

In the report submitted by the F&WS, Pierre, South Dakota, for the reach of the Missouri River from Fort Randall Dam to Ponca, Nebraska, loss of habitat and the aesthetic quality of the structures

used in the demonstration projects were emphasized by the following comments:

(1) The potential for new aquatic habitat could be reduced due to stabilization of the banks.

(2) The greatest loss of terrestrial habitat occurred in understory areas where construction of revetments resulted in the clearing of most low-growing near-bank vegetation.

(3) If the erosion control structures and the cleared areas are revegetated, they provide escape cover and feeding sites for species adapted to early successful stages.

(4) The structures detract from the natural setting, but have been effective in eliminating erosion.

(5) Hard points are the most favorable structure type because the scour hole produced by the structure provides habitat not previously available for fish. The areas between hard points also provide quiet slack-water areas.

State

State Historical Preservation Offices, North Dakota, South Dakota, Nebraska, and Montana; North Dakota State Water Commission; North Dakota Game and Parks Commission; Nebraska Department of Water Resources; Nebraska Game and Parks Commission; South Dakota Department of Natural Resources Development; South Dakota Department of Game, Fish and Parks.

Local

- Nebraska: Lower Niobrara Natural Resources District; Lewis and Clark Natural Resources District; and Missouri River Bank Stabilization Association.
- South Dakota: Yankton County Commission; Clay County Commission; Union County Commission; Dakota Environmental Council; South Eastern Council of Governments; Fort Randall Conservancy Sub-District; Lower James Conservancy Sub-District; Bon Homme County Conservation District; Charles Mix County Conservation District.
- Iowa: Siouxland Interstate Metropolitan Planning Council.

Academic

North Dakota State University, George Washington University.

Exhibit X-7

SUMMARY OF PERTINENT INFORMATION ON MISSOURI RIVER DEMONSTRATION PROJECTS

Erosion Causative Agent: Extended Periods of High Volume Flow Producing High Velociti

Map No.	Missouri River Mile & Side, Local Vicinity, County	At or Near City, State, Cong. Dist., CE Office	Protective Methods Tested (Details Are Shown in Appendix E)	Project Length ft	Costs, $1,000 Construction, Engrg, Monitoring & Reporting
10	868.5 Right Sunshine Bottom Boyd	Butte NE-1 Omaha NE	Intermittent hard points; segmented reinforced revetment types I, II, III; and segmented composite revetment	8,600	631.0 95.0
11	797.0 Right Cedar Co. Park I & II Cedar	St. Helena NE-1 Omaha NE	Intermittent hard points; segmented reinforced revetment types I, II, IV; segmented composite revetment; windrow revetment; and low-grade material utilized	10,300	603.0 135.0
12	784.0 Right Brooky Bottom Road Cedar	Hartington NE-1 Omaha NE	Intermittent hard points; segmented composite revetment types A, B, C, D, E; segmented windrow revetment types I, II; floating plant construction; and low-grade material utilized	18,500	359.0 66.0
13	775.0 Right Mulberry Bend Dixon	Ponca NE-1 Omaha NE	Segmented reinforced revetment types I, II; segmented composite revetment; vane dike; and low-grade material utilized	7,400	428.0 113.0
14	767.0 Right Ryan Bend Dixon	Ponca NE-1 Omaha NE	Segmented reinforced revetment; segmented windrow revetment; segmented composite revetment; and low-grade material utilized	7,500	224.0 61.0
15	761.0 Right Ionia Bend Dixon	Ponca NE-1 Omaha NE	Segmented reinforced revetment types I, II, III; segmented composite revetment; segmented windrow revetment; intermittent hard points; and low-grade material utilized	10,900	847.0 147.0
16	1385.0 Right Hancock Mercer	Stanton ND-1 Omaha NE	Segmented reinforced revetment types II, IV; and segmented composite revetment	6,300	136.0 73.0
17	1374.0 Knife Pt. I Mercer	Stanton ND-1 Omaha NE	Segmented reinforced revetment types II, IV; segmented composite revetment; and segmented windrow revetment type A	3,700	275.0 94.0
18	1379.5 Right Knife Pt. II Mercer	Stanton ND-1 Omaha NE	Intermittent hard points; segmented reinforced revetment types II, IV; and segmented windrow revetment types A, B	3,100	229.0 103.0
19	1368.0 Left Sandstone Bluff I McLean	Washburn ND-1 Omaha NE	Segmented reinforced revetment types II, III	9,300	497.0 64.0
20	1366.5 Left Sandstone Bluff II McLean	Washburn ND-1 Omaha NE	Intermittent hard points; and segmented reinforced revetment types I, II	10,500	500.0 67.0
21	1360.0 Left Coal Lake Coulee McLean	Washburn ND-1 Omaha NE	Reinforced revetment type I; windrow revetment type A; and segmented composite revetment	3,100	219.0 91.0
22	1357.5 Left Lewis & Clark 4-H Camp McLean	Washburn ND-1 Omaha NE	Intermittent hard points; and segmented reinforced revetment types I, II, III	7,100	229.0 49.0
23	1345.2 Left Wildwood McLean	Washburn ND-1 Omaha NE	Reinforced revetment types II, IV; segmented composite revetment; and windrow revetment types A, B	3,100	225.0 92.0
24	1345.0 Right Sanger Oliver	Center ND-1 Omaha NE	Flow control structure--earth core dike; and vegetation planting	[illegible],500	297.0 79.0
25	1343.5 Right Pretty Point Oliver	Center ND-1 Omaha NE	Reinforced revetment type II; segmented composite revetment; and segmented windrow revetment type A	3,000	176.0 129.0

(Continued)

Exhibit X-7 (Concluded)

Map No.	Missouri River Mile & Side, Local Vicinity, County	At or Near City, State, Cong. Dist., CE Office	Protective Methods Tested (Details Are Shown in Appendix E)	Project Length ft	Costs, $1,000 Construction, Engrg, Monitoring & Reporting
26	1341.0 Right Price I Oliver	Center ND-1 Omaha NE	Segmented reinforced revetment types I, II, IV; segmented windrow revetment type A; and segmented composite revetment	8,100	378.0 181.0
27	1338.5 Right Price II Oliver	Center ND-1 Omaha NE	Reinforced revetment types III, IV; and segmented composite revetment	2,700	155.0 83.0
28	1334.5 Right Horseshoe Butte Oliver	Center ND-1 Omaha NE	Reinforced revetment type I; windrow revetment type A; and segmented composite revetment	8,100	342.0 65.0
29	1323.0 Left Eagle Park Burleigh	Bismarck ND-1 Omaha NE	Segmented composite revetment types A, B, D, E; segmented windrow revetment types A, B; intermittent hard points; and tree retards	13,300	545.0 152.0
30	1320.5 Left Burnt Creek Burleigh	Bismarck ND-1 Omaha NE	Segmented reinforced revetment type II; windrow revetment type A; segmented composite revetment; intermittent hard points; flow control structure--earth core dike; and vegetation planting	8,500	518.0 113.0
31	1316.5 Right I-94 Hwy Morton	Mandan ND-1 Omaha NE	Intermittent hard points; rehabilitated hard points; rehabilitated revetment; reinforced revetment type I; windrow revetment type A; segmented composite revetment; and fabricated soil-cement material	11,400	990.0 238.0
32	1311.0 Right Ft. Lincoln Morton	Mandan ND-1 Omaha NE	Rehabilitated revetment; segmented composite revetment; intermittent hard points; and floating plant construction	5,700	238.0 81.0
33	869.0 Left White Swan Charles Mix	Greenwood SD-1 Omaha NE	Intermittent hard points types I, II; segmented windrow revetment types A, B, C; segmented composite revetment types E, F; and segmented reinforced revetment types IV, VI	7,700	357.0 89.0
34	796.5 Left Goat Island Yankton	Yankton SD-1 Omaha NE	Segmented reinforced revetment types I, II, III; segmented composite revetment type II; segmented windrow revetment; and intermittent hard points	12,400	950.0 135.0
35	784.0 Left Vermillion Boat Club Clay	Vermillion SD-1 Omaha NE	Segmented composite revetment; and intermittent hard points	21,600	225.0 63.0
36	771.0 Left Vermillion River Chute Clay	Vermillion SD-1 Omaha NE	Intermittent hard points; segmented reinforced revetment; segmented composite revetment types A, B, C, D, F; and segmented windrow revetment type A	13,100	702.0 143.0
37	754.0 Left Elk Point I & II Union	Elk Point SD-1 Omaha NE	Intermittent hard points types I, II; segmented composite revetment types E, F, G, H, I, J, K, L; segmented reinforced revetment types I, II; segmented windrow revetment; and cellular concrete blocks	17,200	1236.0 174.0

PART XI: YAZOO RIVER BASIN DEMONSTRATION PROJECTS

The Section 32 Program legislation specified conducting demonstration projects in "the delta and hill areas of the Yazoo River Basin generally in accordance with the recommendations of the Chief of Engineers in his report dated September 23, 1972." Demonstration projects were constructed and monitored at numerous sites in 11 general locations in the Yazoo River Basin. In addition to these projects, cooperative efforts with other agencies were arranged to address special areas of interest regarding streambank erosion in the Yazoo River Basin. This work included studies of sediment transport, tests of vegetal covers for possible use in this region, and inventory of bank stabilization methods used by the U. S. Soil Conservation Service. See Exhibit XI-1 for locations of the completed projects. A detailed report on these projects is given in Appendix F.

BANK STABILIZATION

38. Batupan Bogue, Grenada Co. (4 work items)
39. Hunter Creek, Tallahatchie Co. (2 work items)
40. Johnson Creek, Panola Co. (1 work item)
41. N. Fk. Tillatoba Cr., Tallahatchie Co. (2 work items)
42. Perry Creek, Grenada Co. (1 work item)
43. S. Fk. Tillatoba Cr., Tallahatchie Co. (5 work items)

GRADE CONTROL STRUCTURES

44. Goodwin Creek, Panola Co. (3 work items)
45. Hotophia Creek, Panola Co. (1 work item)
46. Johnson Creek, Panola Co. (1 work item)
47. N. Fk. Tillatoba Cr., Tallahatchie Co. (1 work item)
48. Perry Creek, Grenada Co. (1 work item)

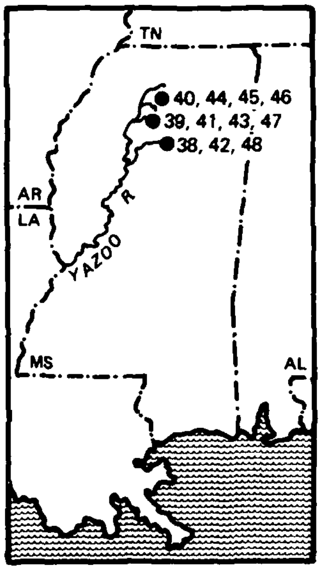


Exhibit XI-1. Locations of Yazoo River Basin demonstration projects

CHANNEL CHARACTERISTICS AND EROSION PROBLEMS

Summary and Range of Streambank (Geotechnical) Characteristics

A wide variation in stream pattern characteristics occurs in the eight Yazoo River Basin hill-line streams that were selected for study under the Section 32 Program. The major reason for these differences is the varying geologic formations the streams flow through. The erosion resistance varies considerably between the formations, as well as within the individual units themselves. Therefore, it is difficult to quantitatively describe the erodibility of the formations; however, a relative comparison among them is possible. The following is a list and brief description of major geologic formations found in the Yazoo River Basin study area, arranged in order of increasing resistance to erosion:

Formation	Description
Loess	Unconsolidated silt
Alluvium	Low-strength sands, gravels, and clays
Kosciusko	Loose sands with traces of silt and clay
Tallahatta	Loose sands interbedded with clays and shales
Citronelle	Mixed sand and clay with gravel lenses
Young paleosol	Semiconsolidated clays
Old paleosol	Dense, consolidated silty, clayey sands
Winona	Consolidated clay, shales, and chalks
Zilpha	Dense clay and clay shales

Summary and Range of Flow (Hydraulic) Characteristics

The drainage areas of the eight watersheds selected for study range from 8 to 230 square miles, and there is a wide variation in the channel geometry and hydraulic characteristics. Rainfall data collected at various locations in the study area indicate an average annual rainfall of approximately 53 in. with a range of 35 to 78 in. Limited stage or discharge data were available for the study areas; however, discharges were estimated using relations between precipitation and runoff.

Causes of Erosion and Failure

The major causes of bank erosion and the failure of protective measures in the Yazoo River Basin have been:

- Bed degradation due to a variety of reasons (channelization, cutoffs, loss of geologic control, flood-control activities, and changes in base level) and the subsequent channel widening.
- Natural meander tendencies of alluvial rivers.
- Bank failures caused by hydrostatic pressure.
- Overbank drainage.
- Man's activities.
- Instability in the streambed and streambanks due to localized geology.
- Extreme storm events.
- Structure alignment p ɔblems (previous revetment and dikes).

Significant Problems Encountered During the Program

- Local cooperation was essential to the success of the Section 32 Program. A majority of the landowners supported efforts to protect their property; however, a few landowners refused and work was deleted from those ownerships.
- Excessive time between initial concept and construction, particularly on the actively degrading streams, resulted in the need for redesign and relocation of planned work.
- Some streams were in transition states and had a geometry that upset sediment movement; this significantly limited the effectiveness of the stabilization efforts.

- During the extremely high flows in November 1977, seven of the bank stabilization structures on Batupan Bogue (Item 4A) were damaged to the extent that reconstruction measures were needed. This event occurred immediately after placement of the structures; however, upper bank protection was incomplete. Bed degradation (especially in the form of local scour), absence of upper bank protection, and the unusually large flows (100- to 500-year frequency event) contributed to the excessive bank failures.
- The funding sequence was not readily compatible with the construction schedule. Late construction starts minimized time available for adequate monitoring at some demonstration sites.
- Limited geologic and soil stratigraphy information was available to adequately incorporate into designs.

TYPES OF PROTECTION INSTALLED AT THE YAZOO RIVER BASIN DEMONSTRATION PROJECTS

General Descriptions

The general physical descriptions of the protective structures used in the Yazoo River Basin are:

Longitudinal stone dikes consist of stone riprap placed parallel to the toe of the streambank and are used to deflect the streamflow and provide toe protection. Areas of the upper bank not covered by stone are sometimes protected by various vegetative treatment methods.

Peaked stone dikes have stone riprap placed parallel to the toe of the streambank and allowed to slope to natural angle of repose. They are used to control the erosion of the toe and induce sedimentation behind the stone. (See Exhibit XI-2.)

Board fences with peaked stone consist of a peaked stone dike along the toe of streambank and reinforced with a treated wood piling and timber fence constructed near top bank height. This type of protection deflects and separates the direct flows on the bank and induces sedimentation between fence and bank. (See Exhibit XI-3.)

Transverse stone dikes are stone-riprap structures protruding from streambank as "hard points," providing some degree of flow deflection, and used as a tieback for longitudinal stone dikes to prevent flanking of structure and provide areas of sedimentation.

Transverse board fence [illegible] are composed of treated wood piling and timber fence protruding from bank to defle[illegible] flows and provide areas of sediment deposition. (See Exhibit XI-4.)

Transverse cable fence dikes have concrete piles with 3/8-in. cables strung between the piling to catch debris and thereby deflect the flows and induce sediment deposition.

Tire revetment is made of used tires tied together with steel banding to form a flexible mattress. The mattress protects the bank from scouring forces of direct flows.

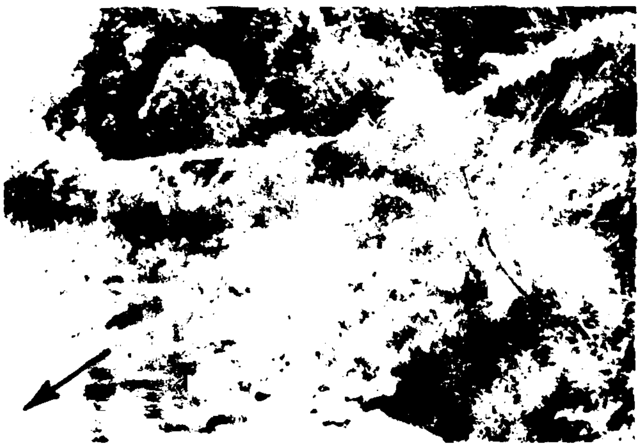
Sand-cement bag revetment consists of biodegradable bags filled with a sand-cement mixture and placed in layers to various bank heights to protect the bank against direct flows.

Wire crib retards, tire-filled, are built of light piling and wire fence cribs placed parallel to the bank and filled with used tires. They deflect flows away from bank and induce sedimentation between the cribs and banks. Some have a stone or sand-cement bag toe protection.

Wire crib retards, hay-filled, are similar to tire cribs but filled with hay ba[illegible]es. (See Exhibit XI-5.)

April 1978
before construction

April 1979,
as constructed



May 1981, two years
after construction

Exhibit XI-2. Peaked stone dike, Johnson Cre[illegible]

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THE STREAMBANK EROSION CONTROL EVALUATION AND DEMONSTRATION ACT--ETC(U)
DEC 81

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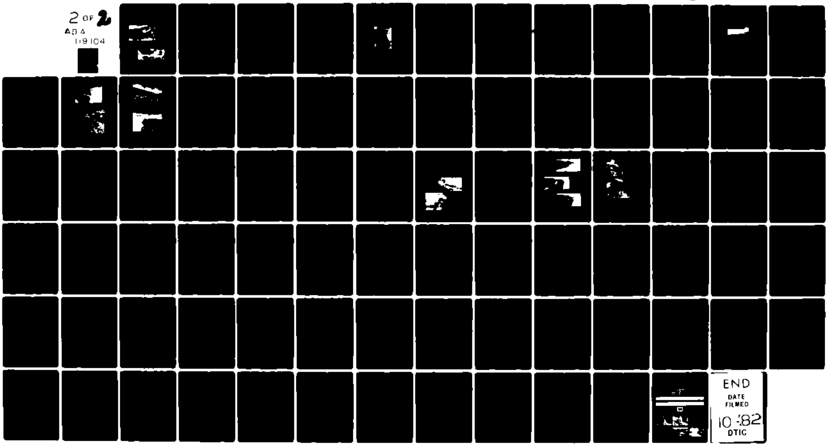


Tire post retards have light piling driven through the center of a stack of used tires, capped with a board railing, and placed parallel to toe of streambank. They are used to divert flows from the bank and induce deposition.

Vegetative treatment consists of seeding with various types of grasses and mulch and or planting of woody vegetation.

Grade-control structures consist of a sheet-pile weir, with an energy-dissipating baffle and a naturally occurring or preformed, riprap-lined scour hole. The purpose of these structures is to halt the migration of head-cuts. Structures built early in the program have scour holes lined with various sizes of graded riprap; but later structures have only the sheet-pile weir and baffle, allowing the forces of the stream to develop the scour hole.(See Exhibits XI-6 and 7.) The Goodwin Creek Watershed grade-control structures were specifically designed to measure total sediment load and discharge, concurrent with the control of bed degradation.

Exhibit XI-6. Grade-control structure, North Fork Tillatoba Creek

Exhibit XI-7. Typical grade-control structure, Johnson Creek. (Scour hole to be formed by hydraulic action)

Relative Costs

Exhibit XI-8 lists the relative construction costs per linear foot of streambank protected (including engineering and design plus supervision and administration) for the various protection techniques used in the Section 32 Program demonstration projects in the Yazoo River Basin.

MONITORING AND OBSERVATIONS OF DEMONSTRATION PROJECTS

Monitoring and observation of the projects consisted of the collection of thalweg and cross-sectional surveys, aerial photography, onsite field inspections, and site surveys. Future monitoring measurements and observations will extend through FY 1982 at some demonstration projects. Subsequent evaluations will be conducted in conjunction with other project activities in the local areas where demonstration projects were constructed.

MAINTENANCE AND REHABILITATION OF DEMONSTRATION PROJECTS

Several periods of high flows (November 1977, March 1978, and May 1980) have caused varying degrees of damage to the demonstration projects. Much of the damage is minor in nature and will require no corrective measures. However, three structures on Batupan Bogue, nine on Perry Creek, four on South Fork Tillatoba Creek, and one on North Fork Tillatoba Creek are severely damaged and are scheduled for rehabilitation work. Some of the rehabilitation work has been completed and the remainder is scheduled for completion in 1981. Some structures have not been tested by a major flood, and other failures will probably occur with time. The contributing factors to the bank failures are bed degradation, misalignment at structures, buildup of hydrostatic pressure in the banks, inadequate toe protection, high flows, and lack of vegetation on upper bank slopes.

SUMMARY OF FINDINGS

Over 220 bendways in eight different drainage basins were stabilized under the Section 32 Program using a variety of different types of stabilization structures. Among the drainage basins considered, there is a wide variation in drainage area, stream characteristics, geology, hydrology, and land-use applications. The short period of time since the construction of the stabilization measures limits the opportunity to observe their effectiveness. However, certain factors related to the construction, design techniques, and general stream characteristics are apparent. Exhibit XI-9 is a summary of the type, cost, and status of the various stabilization techniques used during the Section 32 Program in the Yazoo River Basin

Significant Observations

- A variety of vegetative treatment measures were applied. In cases where existing vegetation was left undisturbed, the effectiveness of bank protection was increased. This was especially true in cases where woody vegetation existed. In some cases it was necessary to use vegetative treatment to help stabilize banks that had been graded or banks that were void of vegetation. The effectiveness of these vegetative treatments generally depended on whether or not the vegetation had been given time to take hold prior to the high-water season. The use of woody vegetation such as willow seemed to provide a more effective bank protection than nonwoody vegetation; however, in time,

Exhibit XI-8

YAZOO RIVER BASIN DEMONSTRATION PROJECTS

Relative Construction Costs

Dollar per Linear Foot of Bank Protected

(Includes Engineering and Design, and Supervision and Administration)

Type of Work / Project / Item No. / Map No.	Batupan Bogue FY 74 38	Batupan Bogue 4A 38	Batupan Bogue 4A-1 38	Batupan Bogue 4A-2 38	Hired Labor FY 80 --	Hunter Creek 1A 39	Johnson Creek 9 40	Perry Creek 6A 42	Tillatoba & Hunter Cr 1 39, 41	Tillatoba Creek, NF 2 41	Tillatoba Creek, SF FY 72 43	Tillatoba Creek, SF FY 73 43	Tillatoba Creek, SF 5A 43	Tillatoba Creek, SF 5B 43	Tillatoba Creek, SF 5C 43
Transverse stone dike	30		43			36			31	31	38	48			
Longitudinal stone dike w/tieback	142	50							53	55	101	101			
Longitudinal stone dike w/2 tiebacks									72	56					
Longitudinal stone dike w/more tiebacks									86	58					
Type I stone dike									45						
Type I longitudinal stone dike w/1 type I tieback						24		25	26						
Type I longitudinal stone dike w/more than 1 type I tieback						32			41						
Type II longitudinal stone dike w/1 tieback			43			56		37	63						51
Type III longitudinal stone dike w/1 tieback			72												85
Longitudinal peaked stone dikes II		39	43				57	37							68
Longitudinal peaked stone dikes III			86				86								102
Stone paving			50					31		27					
Used tire revetment		36	24										43		43
Sand-cement bag revetment		81											129		
Tire post retards								15							
Wire crib retards								29*						33** 33*	
Board fence transverse dike	34											49			
Board fence longitudinal revetment	150														
Cable fence dikes												58			
Vegetative treatment or willow planting				12	4										
Longitudinal peaked stone dike I							14								

* Tire.
** Hay.

Exhibit XI-9

SUMMARY OF YAZOO BASIN DEMONSTRATION PROJECTS

Map No.	Item	Fiscal Year	Construction Cost in $1,000	Types of Work	Status of Work
43	South Fork Tillatoba Creek, Item FY 72	72	237.7	Transverse and longitudinal stone dikes	Structures performing satisfactorily.
43	South Fork Tillatoba Creek, Item FY 73	73	222.9	Transverse and longitudinal stone dikes, cable fence dikes, and board fence dikes	Structures performing satisfactorily, minor erosional problem noted.
38	Batupan Bogue, Item FY 74	74	565.0	Board fence dikes and board fence revetment	Structures performing satisfactorily.
39, 41	North Fork Tillatoba and Hunter Creeks, Item No. 1	76-77	626.0	Transverse and longitudinal stone dikes	Hunter Creek--structures performing satisfactorily; North Fork Tillatoba--majority of structures performing satisfactorily; channel instability has caused some problems.
41	North Fork Tillatoba Creek, Item No. 2	76-77	530.0	Transverse and longitudinal stone dikes and stone bank paving	Majority of structures performing satisfactorily; channel instability has caused some problems.
39	Hunter Creek, Item 1A	77	112.0	Transverse and longitudinal stone dikes	Structures performing satisfactorily.
43	South Fork Tillatoba Creek, Item 5A (HL)	77	100.0	Used tire and sand-cement bag revetment	Structures performing satisfactorily, with exception of slip failure on sand-cement bag revetment.
43	South Fork Tillatoba Creek, Item 5B	77	161.0	Wire crib retards filled with used tires or hay	Structures failed soon after construction.
47	North Fork Tillatoba Creek, Item 3C	77	128.4	Stone grade-control structure with sheet-pile cut-off wall and H-pile baffle	Structure performing satisfactorily.
47	North Fork Tillatoba Creek, Item 3A	77-78 79-80	210.0	Stone grade-control structure with sheet-pile cut-off wall and sheet-pile baffle filled with grouted riprap	Structure performing satisfactorily.
38	Batupan Bogue, Item 4A	77-78 79-80	946.0	Longitudinal stone dike, used tire revetment, and sand-cement bag revetment	Majority of structures failed during high runouts in Nov 77; rehab. Work performed under Work Item 4A-1
42	Perry Creek, Item 6A	78	432.0	Longitudinal stone dike, wire crib retards filled with used tires, and used tire post retards	Majority of structures performing satisfactorily; degradation has adversely affected performance of some structures.
43	South Fork Tillatoba Creek, Item 5C	78	456.0	Longitudinal stone dikes with stone tiebacks and used tire revetment	Majority of structures performing satisfactorily; degradation has adversely affected performance of some structures.
48	Perry Creek, Item 6B	78	702.0	Two stone grade-control structures - one with sheet-pile baffle and one with H-pile baffle	Lower structure is performing satisfactorily; upper structure is endangered by erosion of upstream left bank.
38	Batupan Bogue, Item 4A-1	78-79	498.0	Used tire revetment, vegetative treatment and stone tiebacks	Majority of structures performing satisfactorily; however erosional problems still exist.
44	Goodwin Creek, Item 8B	78-79	736.0	Three grade-control structures	Structures integrity OK; data collection system not operational.
--	Vegetation, Items 12A and 12ARS Agreement	78-79-80	632.0	Vegetative treatment	Construction completed, spring 1981.
38	Vegetation, Batupan Bogue, Item 4A-2	79	64.0	Vegetative treatment (work performed by minority contractor)	Vegetation has been established; however some erosional problems noted.
40	Johnson Creek, Item 9A	79	177.0	Longitudinal peaked stone dikes 1/2, 2, and 3 tons stone per lin ft	Structures performing satisfactorily (minimum protection work)
44	Goodwin Creek, Item 8A	79-80	286.0	One grade-control structure	Structure integrity OK; data collection system not operational.
44	Goodwin Creek, Item 8C	79-80	865.0	Ten grade-control structures	Structures integrity OK; data collection system not operational.
46	Johnson Creek, Item 9B	80	152.0	Three minimum grade-control structures (work performed by minority contractor)	Numerous construction delays; not yet accepted by Vicksburg District.
45	Hotophia Creek, Item 7	80	252.0	Five minimum grade-control structures	Structures performing satisfactorily.
	TOTAL		9,091.0		

woody vegetation could impede flows unless its growth is controlled. It is important to note that in some cases the soils (paleosols, Zilpha, etc.) are not conducive to vegetative growth.

- Since bed degradation is very widespread in the Yazoo hill streams, the protection of the bank toe appears to be an important factor in the design of bank stabilization measures. The longitudinal stone dikes that provided effective toe protection were the most successful bank stabilization measures studied, particularly in degrading streams. The success of the longitudinal stone dikes is exemplified on Hunter Creek (Exhibit XI-10) where the structures have effectively protected the bed and banks and thereby established a stable system. In many cases the absence of toe protection (tire post retards on Perry Creek) contributed to the bank failures. Bank stabilization measures without toe protection were successful in some instances; however, if bed degradation is apparent or anticipated, or in bends having more than slight curvature, then toe protection is needed or structures must be designed to accommodate expected channel deepening.

Exhibit XI-10. Longitudinal stone dike, Hunter Creek

- Numerous usable geologic controls (consolidated clays in the streambed, outcrops of ironstone, quartzite, etc.) were encountered during the study. In general, the presence of geologic controls has a stabilizing effect on the stream by halting the upstream migration of head-cuts; however, there are times when a well-consolidated streambed may actually contribute to the erosion of the upper banks. This was the case on Batupan Bogue (Item 4A) where the streambed consisted of a well-consolidated clay. During the extreme flow in November 1977, the stream "skated" over the resistant clay bed and scoured the upper banks to over twice their original width.

- The grade-control structures have proven quite effective in halting streambed degradation although there have been some minor erosional problems encountered at a few sites. In some instances (Perry Creek upper structure), it appears that the degradation has been halted by the riprap key downstream of the preformed scour pocket. At other locations in the study area, degradation has been temporarily halted by box culverts and the placement of concrete rubble in the streambed by the local landowner; however, it should be emphasized that these techniques are only temporary and should not be considered as a method of halting bed degradation permanently.

- Even under the best design conditions, the effectiveness of the stabilization measure may be nullified due to construction delays. During the study, several instances of changes in stream patterns and bed elevation occurred from the time of design survey to construction. This was the case on North Fork Tillatoba Creek (Item 1) where the low-water thalweg pattern reversed in a sine-cosine fashion. On Johnson Creek a head-cut had already progressed upstream of the site of the proposed grade-control structure, thereby severely limiting the effectiveness of the structure.

- Monolithic-type bank stabilization structures prevent the seepage of water through the bank, thereby creating hydrostatic pressures in the banks. If pressure release is not provided, mass bank and structural failures may occur. This was the case of the slip failure that occurred on South Fork Tillatoba Creek where sand-cement bag revetment was installed. After placement of the sand-cement bags, the structure acquired the characteristics of a monolithic structure and a slip failure of the bank occurred, possibly due to the buildup of hydrostatic pressure following a bank-full event.

- Scour pockets were observed at the downstream edge of some structures as a result of the eddy action of the water flowing over the downstream stone tiebacks. Similar scour was observed at the point of transition from complete upper bank paving to longitudinal stone toe protection. Careful consideration during design is needed to minimize this scouring action where stabilization measures are terminated (at both upstream and downstream ends).

- It is noteworthy that none of the bank protection works in the Yazoo River Basin, except at grade-control structures, included a filter layer or filter fabric. With a few exceptions, this lack of a filter did not significantly affect the performance of the works. These few exceptions, of course, occurred where strata in the bank material were relatively impermeable, the groundwater level was high, and/or the revetment structure tended to act as a monolith (sacked sand-cement). The significance of this observation is that the designer of bank protection works should not automatically specify expensive filter material if the risk and consequences of loss of minor amounts of bank material through the protective covering are small. Where the bank material is pervious, groundwater level is low, the duration of high stages is short, and the revetment material is flexible and pervious (i.e. riprap), a filter may not be cost-effective.

- Throughout the program it became apparent that some streams responded more effectively to bank stabilization measures than others. This phenomenon may be attributed to the rapid rate of change of the morphologic parameters (width, depth, etc.) in the unstable streams. Streams that have been significantly altered due to bed degradation undergo a rapid rate of change in width, depth, and other channel parameters. After a certain period of time, this rate of change decreases as the stream begins to adjust to a new state of relative equilibrium. It is during this period of adjustment toward a new equilibrium state that bank stabilization measures have the greatest chance of success. Construction to stabilize the stream during the rapid transition state will require more massive and costly protective works to compensate for the increased threat.

Recommendations

- The alignment of the structures is critical. During periods of high and low flows, the location of the major point of attack will vary. It is therefore necessary to define the limits for this point of attack in order to provide adequate bank protection for both high and low flows. The design should provide the highest degree of protection within the limits of the point of attack of high flows with a reduced level of protection upstream and downstream. The most common oversight in design is to extend bank protection too far upstream and not far enough downstream Since bends migrate downvalley, the downstream end of the protection is more critical; therefore, care should be taken in establishing the lower limits of protection.

- The alignment of the structures should provide a smooth transition from bendway to bendway. Both the high-water and low-water paths should be considered in alignment design for development of an orderly transition between bendways, thereby preventing the structures from creating an obstruction to flow. In instances where the structure alignment was not compatible with the high-water flows (upper seven structures on Item 1, North Fork Tillatoba Creek), the structures were subjected to erosive forces that resulted in upper bank failure. On the other hand, the minimum protection on Johnson Creek was designed to create a smooth transition between bendways for both high and low flows and the structures have effectively stabilized the banks. Before and after photographs of a typical Johnson Creek bendway are shown in Exhibit XI-2.

- In streams where the streambed consists of a well-consolidated clay or other geologic control, the stabilization measures should be designed to provide complete upper bank protection with only minimum toe protection. This differs from the design on actively degrading streams such as Perry Creek where toe protection is essential to the success of the structure.

- All possible measures should be taken to expedite the time between design and construction. An effective way to do this is to advertise and award the contract based on generalized design, site layouts, and approximate quantities, then furnish detailed site layouts and cross sections immediately prior to construction.

- Close coordination between design and construction personnel while work is under way is very important. This is exemplified on Johnson Creek (Item 9A) where a protruding clay plug in the bank was encountered during placement of the stone toe protection. Rather than removing the obstruction and aligning the structure as designed, the stone was placed along the protruding bank line, thereby creating a point of discontinuity in the structure. Onsite changes by construction personnel are sometimes necessary but should be closely coordinated with the designers.

- Where possible, natural levees along top bank should be left undisturbed by construction activities. Man-made replacements may not be adequate and may alter the overbank drainage patterns. Engineering techniques to control overbank drainage are necessary to prevent damage to the structure.

- Before any stabilization measures are planned, as much data as are available should be analyzed. This may be accomplished through a research of old plan maps, surveys, topographic maps, aerial photographs, field investigations, discussions with local residents, and historical documentation of the area. This will assist designers to understand how the system has responded to changes in the past and how it may respond in the future.

- It should be emphasized that since this project was somewhat experimental, failures were expected. Some structures were designed with marginal strength in an effort to determine

the minimum amount of protection required to demonstrate that using inexpensive measures can in some cases be false economy. There is a most important difference between "inexpensive" work and "cost-effective" work; "cheap" solutions to significant erosion problems are not possible. However, an understanding of the stream's behavior allows the most cost-effective use of resources, even though the cost may be significant or even prohibitive.

SIGNIFICANT PARTICIPATION BY OTHER ORGANIZATIONS

Federal

A joint venture was undertaken with the USDA Science and Education Administration Sedimentation Laboratory (SEA) at Oxford, Mississippi, to define and monitor amounts, sources, direction, and time of travel of sediments. Research included complete analyses of the drainage basin morphology, geology, soils, land use, vegetation, basin stratigraphy, hydrology, climatology, and stream hydraulics. Particular emphasis was given to the Goodwin Creek Basin, and the results will be used to determine the performance of selected channel stabilization methods and to determine influence of grade-control structures on channel stability.

The SEA and the USDA Soil Conservation Service (SCS) have cooperated in a program testing the effectiveness of a wide variety of vegetation controls on streambank stability.

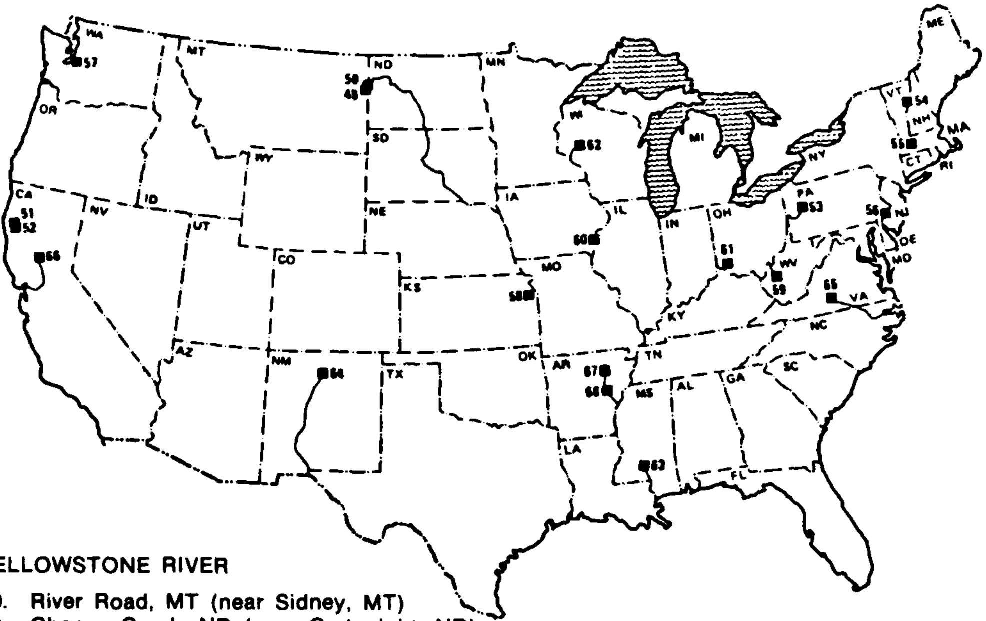
The SCS inventory and evaluation of bank stabilization measures in North Mississippi lists 326 sites that were stabilized. Of these sites, SCS lists only 11 percent as having failed to some degree; however, photographs and surveys furnished with this report indicate a much higher percent with problems. Prior to using this SCS report to substantiate erosion problems and stabilization measures in the Yazoo River Basin, a more thorough analysis of the SCS work is needed.

Local

Local sponsors for the demonstration projects in the Yazoo River Basin were, respective to the listing of locations in Exhibit XI-1: (38, 42,48) Grenada County; (39, 41, 43, 47) Tallahatchie County and North Tillatoba Drainage District; (40, 44, 46) Long Creek Drainage District; and (45) Hotophia Creek Drainage District.

PART XII: DEMONSTRATION PROJECTS ON OTHER STREAMS, NATIONWIDE

A variety of streambank protection methods and materials were evaluated at other selected sites nationwide to demonstrate their capability to perform under a broad range of geographical and environmental conditions. This group of projects was composed primarily of demonstration projects that were not specified by the original Section 32 Program legislation. The Eel and Yellowstone River sites are exceptions that were added as an amendment in 1976 to Section 32 of Public Law 93-251 and were included in this group for reporting purposes. Twenty projects on sixteen different streams throughout the United States were constructed and monitored. Included were sites where streambank loss is the result of flow velocity, wave action, ice scour, water-surface fluctuation, and/or bank instability. See Exhibit XII-1 for locations of the completed projects. Exhibit XII-7 at the end of this part presents brief summaries of these demonstration sites on other streams, nationwide. A detailed report on these projects is given in Appendix G.



YELLOWSTONE RIVER

49. River Road, MT (near Sidney, MT)
50. Cheney Creek, ND (near Cartwright, ND)

EEL RIVER DELTA

51. Eel River, Fernbridge, CA
52. Van Duzen River, Carlotta, CA

PROJECTS ON OTHER STREAMS, NATIONWIDE

53. Allegheny River, Wattersonville, PA
54. Connecticut River, Haverhill, NH
55. Connecticut River, Northfield, MA
56. Delaware River, Paulsboro, NJ
57. Green River, Kent, WA
58. Kansas River, Eudora, KS
59. Kanawha River, South Charleston, WV
60. Iowa River, Wapello, IA
61. Little Miami River, Milford, OH
62. Lower Chippewa River, Eau Claire, WI (5 sites)
63. Pearl River, Monticello, MS (3 sites)
64. Rio Chama, Abiquiu, NM
65. Roanoke River, Leesville, VA (2 sites)
66. Sacramento River, Ordbend, CA
67. White River, Jacksonport, AR
68. White River, Des Arc, AR

Exhibit XII-1. Locations of demonstration projects on other streams, nationwide

CHANNEL CHARACTERISTICS AND EROSION PROBLEMS

Summary and Range of Streambank (Geotechnical) and Flow (Hydraulic) Characteristics

The geotechnical and hydraulic conditions at the 20 sites are indicated in Exhibit XII-7. Riverbanks are from 3 to 100 ft high and are composed primarily of alluvial and eolian soil deposits of Recent age. The soils are often stratified with interbedded layers of coarse-grained (sand and gravel) and fine-grained (silt and clay) materials. Flows in the streams vary from 0 to over 500,000 cfs, and velocities varied from 0 to 14 fps. River slopes varied from very flat up to 11 ft/mile. Two sites are in the tidal influence of the ocean.

Causes of Erosion and Failures

There is seldom a single cause for the recession of a riverbank. Therefore, to present definitive answers or to indicate a ranking of possible causes would in all cases be difficult. A review of the site conditions and the responses of these conditions to the natural and imposed forces is helpful to develop an understanding of the mechanics of the problem. Each site is unique and therefore must be studied separately to isolate the probable causes for bank recession. A summary of the causes of erosion and failures encountered in these 20 projects follows:

- Streambank erosion from the removal of soil particles by flowing water was one of the major failure mechanisms encountered. Theoretical and empirical techniques have long been available to determine the particle size and weight necessary to resist erosion due to shear or drag. However, a great deal is still to be learned about drag and lift forces due to turbulent, high-velocity flow and their effect on the stability of quarry-run stone or riverbed material and on articulated, anchored, and cemented surfaces.

- Geotechnical aspects associated with bank instability and related erosion problems and realization of their importance were significant findings of the program. Though understood technically, these conditions were sometimes overlooked. Many of the riverbanks studied are alluvial deposits laid down in riverbeds, floodplains, and lakes during Recent geologic time. As a result, the soil deposits consist of interbedded layers of coarse- and fine-grained soils. The particle size of the material is dependent on the velocity of the flowing water at the time of deposition. Valley cutting by the river has exposed the bank revealing a cross section through the layers of soil. Coarse sands and gravel layers are interbedded with silts and clays of variable thickness in the exposed bank. When the present river rises above the normal groundwater level in the area during high riverflows or for other reasons, the bank becomes saturated. The coarse-grained soils transmit the water into the bank a greater distance than the finer layers, because of the greater permeability or transmissibility of the coarser material. If the drawdown of the river occurs at a faster rate than the soil layer can expel the water that seeped into it, an excess hydrostatic pressure develops within the bank. Saturation can also result from water infiltration into the bank and upland areas. This causes additional forces within the slope acting in a driving direction to cause the slope to move outward. If the in situ shear strength that existed in the bank prior to saturation or that reduced by saturation effects is inadequate to resist these additional hydrostatic and weight forces, the bank fails or sloughs on the weakened surface to a flatter, more stable slope. Sometimes the bank is stable, but the water stored within the coarse layers flows out to the river at a rate that when sufficient, causes the outside particles to flow out and down the bank. This develops holes on the bank surfaces and is referred to as piping. When the pipes are sufficiently developed, the bank is undermined and collapses. The materials that fall into the river are washed away, starting the cycle over again.

- Floating ice and debris (trees, lumber, etc.) and gouging from ice jams are significant causes of erosion and causes for damage to erosion control structures. Ice problems are confined to colder climate areas, whereas floating debris problems are prevalent on all medium- to high-velocity streams.
- Waves from passing vessels and waves generated by wind stresses were the major cause for erosion at one test site.
- Overbank flow of water from upland areas over the banks into the river and streams causes gullies that degrade and weaken the slope. (See Exhibit XII-2.)

Exhibit XII-2. Typical erosion from surface runoff, Green River, Washington

TYPES OF PROTECTION INSTALLED AT DEMONSTRATION PROJECTS

As diverse as the nationwide site conditions are, the protective schemes used were even more varied. General guidance was provided to the Corps District designers, but a maximum degree of freedom was allowed to encourage ingenuity and develop cost-effective installations with locally available, low-cost materials. A few of the test sections are shown in Exhibits XII-3 to XII-6.

General Descriptions and Relative Costs

The protection systems used are divided below into two broad categories—flow redirection structures (12 items) and bank protection structures (22 items). Unit cost ranges for construction are presented adjacent to each type for the unit bank length protected. More specific costs and unit costs are presented in Exhibit XII-7 and in the project report for each site (Appendix G). Caution should be used when applying the indicated unit costs to other sites because of differing site conditions and material availability. Engineering and design (E&D) and supervision and administration (S&A) costs are included in the total costs. The projects were constructed by private firms under contract to the Corps. As a result, the unit costs of apparently economic techniques often were high because the construction was highly labor-intensive. However, in a self-help situation with minimal labor costs and low-cost materials, these more promising techniques should be more cost-effective.

Flow Redirection Structures Perpendicular or at an Angle to the Riverbank	Cost Ranges \$/ft of Bank Protected
- Sand dike with gravel core and cover, vegetated	35
- Rock hard points, at various spacings, into the river or in the banks	24-138
- Gabion groins (dikes)—wire baskets filled with stone and gravel	93
- Permeable timber fence or wire fence dikes at various spacings with pile supports	115
- Concrete pile hard points—concrete piles formed together in the banks with a concrete cap	900
- Nylon sand-filled bag groins (dikes)	103
- Longard tube groins (dikes)—48-in.-diam nylon tubes of various lengths filled with sand	56
- Tree pendants—dead trees from along the river, dragged and pushed into place in front of the eroding banks and anchored to the bank	73

Flow Redirection Structures Parallel to and Offset from the Riverbank	Cost Ranges \$/ft of Bank Protected
- Permeable timber or wire mesh fence, pile-supported with and without brush backfill to bank	22-341
- Tree pendants—dead trees from along the river, dragged and pushed into place in front of the eroding banks and anchored to the bank	15-19
- Floating tire breakwater—used tires filled with buoyant material and tied together to form a wave breakwater. (See Exhibit XII-3)	270
- Kellner jacks—steel angles bolted together at the midpoint in a shape like a jack and wired together in the river, parallel to the shore. (When used parallel and perpendicular to the bank, the system is referred to as a Kellner Jack Field)	85

Bank Protection Structures	Cost Ranges \$/ft of Bank Protected
- Rock-fill toe with various inexpensive, upper-bank protective systems and vegetation	65-520
- Rock-fill stability berm to correct a bank instability problem with various upper-bank protection systems	111-163
- Wood and wire fence anchored to the bank	25
- Gabion dike at toe of slope and backfilled to the slope	515

(Continued)

Bank Protection Structures (Concluded)	Cost Ranges \$ ft of Bank Protected
- Stone-fill dike at toe of slope and backfilled to the slope with and without upper-bank protection	117-450
- Windrow trenches—trenches at the top of bank in which stones are placed at varying rates to fall down the slope as erosion of the bank occurs	34-116
- Gabion mattress—interlaced wire mesh baskets filled with river cobbles or crushed rock, with and without filter fabric underlayment and upper-bank vegetation. (See Exhibit XII-4)	107-211
- Used tire mattress with earth or stone fill; with and without filter fabric underlayment; upper bank vegetated (See Exhibit XII-5)	61-683
- Sand- and sand-cement filled bags with filter fabric underlayment and upper bank vegetation	58-113
- Baled hay with and without filter fabric underlayment; upper bank vegetated	109-113
- Precast cellular concrete block mattress with filter fabric underlayment; upper bank vegetation. (See Exhibit XII-6)	65-471
- Used tire wall with or without filter fabric; upper bank vegetated	124-164
- Used tire wall, pile-supported, with or without filter fabric	174
- Soil-cement blanket—a mixture of the natural soil and cement compacted in place	365-643
- Grout-filled mats (e.g., Fabriform)	154-647
- Concrete and log crib walls—an interlacing of concrete beams or logs to form a box and backfilled	625
- Filter fabric matting anchored at toe and top of bank, and randomly between on the slope	55
- Enkamat—a patented product to promote vegetative growth	79-87
- Dumped rubble—coarse concrete and brick material from building debris	164-381
- Riprap blanket—Corps criteria and quarry-run stone	50-233
- Wire-mesh-lined, log cribs filled with river cobbles	223
- Vegetated slope only	50

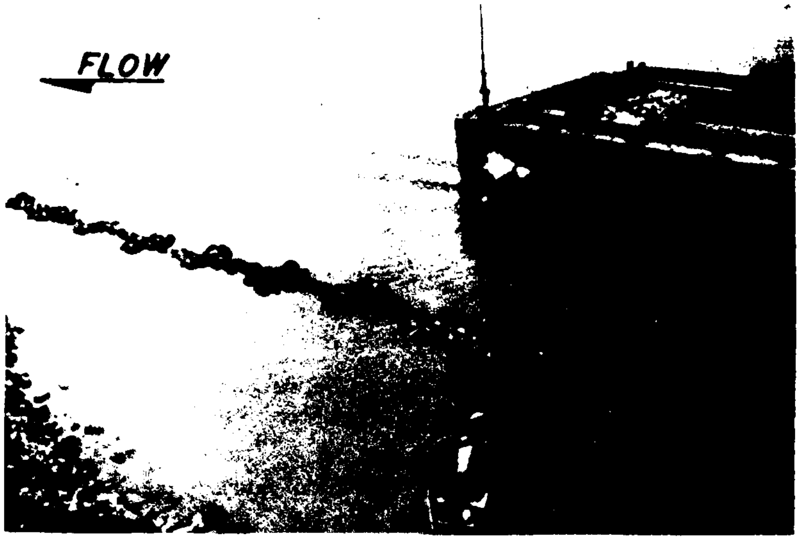


Exhibit XII-3. Floating tire breakwater, Kanawha River, West Virginia (damaged by debris and impacts of tow traffic)

Exhibit XII-4. Gabion revetment, Delaware River, New Jersey

Exhibit XII-5. Tire mattress with rock toe, Roanoke (Staunton) River, Virginia

Exhibit XII-6. Gobimat revetment, Connecticut River, Massachusetts

MONITORING AND OBSERVATIONS OF DEMONSTRATION PROJECTS

The key to evaluating a particular scheme at a specific site is the monitoring and observation program established before, during, and after construction. Many sites did not have a sufficiently long period of observation after construction, or were not subject to a severe enough event to test the installation; these are indicated in Exhibit XII-7. Some of the monitoring and obsevation procedures used are visual inspections, ground and aerial photography, velocity and flow measurements, wave measurements, vessel character and traffic counts, river stage recording, test borings, and piezometer readings.

MAINTENANCE AND REHABILITATION OF DEMONSTRATION PROJECTS

Some of the erosion protective systems used under this program are low-cost schemes that are designed to protect the bank against a limited number of critical events or to mitigate the damages of a specific event. As a result, a higher level of maintenance will be required throughout the life of the structure. If these structures are permitted to degrade, the eroded bank condition will redevelop. The cost of the maintenance and rehabilitation cannot be predicted accurately at this time because of the uncertainty of the severity of the events that may occur and the response of the structures and banks to the events. The repair of damage to structures that control overland drainage must not be overlooked.

SUMMARY OF FINDINGS

Many of the structures constructed under the nationwide program have not experienced critical streamflow events to permit an assessment of their behavior and effectiveness. Generally, these demonstration projects were not constructed until later on in the Section 32 Program. Therefore, only generalized and preliminary evaluations can be formulated and presented.

Significant Observations

- Areas left unprotected between protection structures or on the upper bank are frequently subject to erosion. This develops a scalloping effect between hard points which can be held to acceptable limits by proper spacing of the hard points along the riverbank.
- Floating ice and debris uplifted and pushed down timber and wire fence dikes and Kellner Jack Fields. They also submerged the floating tire breakwater. Stone used in the outer edge of a few dike hard points was dislodged by the ice jam and flows.
- Rock toe protection when constructed with low-cost, upper bank protection generally functioned satisfactorily against the events experienced to date.
- No difference in performance was noted between protective covers placed with or without filters.
- Trees used as pendants adjacent to the riverbank are difficult to transport to the site without damage to the roots and limbs needed for protection. The effectiveness of this type of protective system remains to be evaluated.
- Mulching grass-seeded slopes with hay and plastic netting aided the establishment of the grass.

Conclusions

- Wire mesh matting is ineffective in providing interim erosion protection for establishment of vegetative growth.
- Piping of soil on drawdown or from normal perched water flows observed at some projects required a filter material to prevent the washing of the natural soil through the blanket protection provided.
- Geotechnical problems associated with a specific site must not be overlooked and an adequate design provided to maintain slope stability for the normal condition, the eroded channel bed condition, and drawdown conditions.
- Toe protection is an essential part of successful bank protection.
- Simply grading the streambank to a stable slope and planting vegetation without toe protection is ineffective.

Recommendations

- Mulching, turfing, and other vegetation systems should be specified to provide a protective slope cover where possible. The vegetation should be planted at the beginning of the growing season and reseeded or replanted as necessary until established.
- Overbank drainage from interior areas must be controlled. The water must not be permitted to flow over and down the slope. Outlets should be provided where required to conduct the water to the river.
- Vandalism in urban areas is a problem and should be considered in the design and selection of protective systems. Fires, cutting with knives, etc., should be anticipated.
- Stone fill should be used in rubber tire mattresses rather than random earth fill.

SIGNIFICANT PARTICIPATION BY OTHER ORGANIZATIONS

Local sponsors for the demonstration projects on other streams, nationwide, respective to the listing of locations in Exhibit XII-1, were: (49) Richland County, Montana; (50) North Dakota State Water Commission; (51) County of Humboldt, California; (52) County of Humboldt, California; (53) County of Armstrong, Pennsylvania; (54) State of New Hampshire Water Resources Board; (55) Commonwealth of Massachusetts Department of Environmental Quality Engineering; (56) Borough of Paulsboro, New Jersey; (57) King County, Washington; (58) Fall Leaf Bottoms Drainage District, Kansas; (59) City of South Charleston, West Virginia; (60) City of Wapello, Iowa; (61) City of Milford, Ohio; (62) Dunn County, Wisconsin; (63) Pearl River Basin Development District, Mississippi; (64) La Asociacion De Santa Rosa De Lima De Abiquiu, Inc., New Mexico; (65) Pittsylvania Soil and Water Conservation District, Virginia; (66) Board of Reclamation, State of California; (67) Arkansas State Park Recreation and Travel Commission; and (68) City of Des Arc, Arkansas.

Exhibit XII-7

SUMMARY OF DEMONSTRATION PROJECTS ON OTHER STREAMS, NATIONWIDE

Map No.	Stream, Mile and Side, Local Vicinity, County	At or Near City, State, Cong. Dist., CE Office	Project Site Conditions: Riverbank (Geotechnical)	Project Site Conditions: Flow (Hydraulic)	Project Site Conditions: Erosion Agent
49	Yellowstone R. 27.5 Right River Road Richland	Sidney MT-2 Omaha NE	Silt, occasional lenses sand and clay. Height - 8 ft. Slope - vertical to 1V on 1H.	Velocity, 6 fps; river slope 1 to 2 ft/mile	Current velocity at sharp angle, plus ice gouging
50	Yellowstone R. 20.0 Right Cheney Creek McKenzie	Cartwright ND-1 Omaha NE	Silt and clay over a layer of coarse sand over fine sand. Height - 20 ft. Slope - vertical to flat at river.	Concave band with velocity of 6-8 fps	Current velocity, wind waves, bank saturation, and ice gouging
51	Eel R. 6.0 Right D/S of Fernbridge Humboldt	Fortuna CA-2 San Francisco CA	Silt over layers of loose silty gravel and gravelly sand. Height - 20 ft. Slope - vertical to 1V on 2H	Peak velocity 10-14 fps; river slope 4 ft/mile	Loss of toe with subsequent slough of upper bank, and saturation of upper bank. Floating debris also damages bank on occasion
52	Van Duzen R. 8.0 Right D/S of Fielder Creek Humboldt	Carlotta CA-2 San Francisco CA	Silt and gravel. Height - 15 ft. Slope - vertical to 1V on 1.5H	Design velocity 10 fps; river slope 11 ft/mile	Current velocity in steep gradient stream. Upstream slide directed flow into bank
53	Allegheny R. 62.4 Right U/S of L&D 9 Armstrong	Watterson-ville PA-12 Pittsburgh PA	Fine gravel (clayey silt) alluvium layers with sand. Height - 3 to 15 ft. Slope - vertical to 1V on 2H	Peak velocity 7 fps; river slope 1 ft/mile Downstream tangent of river bend; massive ice flows	Bank saturation during high flow and sloughing with subsequent drawdown and piping; some current velocity and ice scour
54	Connecticut R. 254.6 Left Dean Thornburn Farm Grafton	Haverhill NH-2 New England MA	Material (typical) - 0-10 ft fine sandy silt (ML), nonplastic; 10-20 ft silty fine sand (SM); 20-30 ft silty, med-fine sand (SP-SM). Height - 20 ft. Slope - range 1V on 1.25H to 1V on 1.5H	Velocity, normal <2 fps; high flow 7-8 fps; river slope normal 0.1 ft/mile; high 0.2 ft/mile	Tractive force, ice, pool fluctuations, bank seepage, boat waves, overbank drainage

	Types of Protection Tested	Lengths, ft, Bank, Structure	Total Costs, $/1000's, Contract, E&D, S&A, Total	Unit Cost $/ft of Length Contract and Total Bank	Structure	Date Constr.	Remarks and/or Conclusions
1.	Sand dike with gravel core and cover and vegetated	3500 600	52.0 63.5 7.5 123.0	15 35	87 205	Dec 1980	Insufficient time to evaluate. Evaluation will be furnished in supplemental report
1.	Riprap rock toe, with crown cap of 2-ft mix of random rock and fill, willow slash vegetated	2400 2400	403.1 73.7 11.8 488.6	168 204	168 204	Dec 1980	Insufficient time to evaluate. Evaluation will be furnished in supplemental report
1.	Rock hard points spaced 40 ft on center	800 800	81.6 18.2 10.6 110.4	102 138	102 138	Sep 1979	Overall performance successful, no damage to the protection. Scalloping between rock hard points, as anticipated. Erosion occurred at upstream tie-back of wire mesh pile fence and at downstream of rock toe protection. Both repaired and are functioning satisfactorily
2.	Pile-supported wire mesh fence parallel to bank and rock toe, piles - 12-ft spacing (light)	400 400	78.4 18.2 10.6 107.2	196 268	196 268	Sep 1979	
3.	Same as 2 but piles 6-ft spacing (dense)	400 400	107.6 18.2 10.6 136.4	269 341	269 341	Sep 1979	
4.	Rock toe protection with upper bank vegetation	900 900	104.4 18.2 10.6 133.2	116 148	116 148	Sep 1979	
1.	Tree pendants anchored to shore	300 300	4.5 11.0 6.4 21.9	15 73	15 73	Nov 1978	Performance satisfactory. Transport of trees causes limb and root breakage which reduces effectiveness to some degree.
2.	Wire-mesh-pile supported fence 12-ft spacing (light)	300 300	33.0 11.0 6.4 50.4	110 168	110 168	Nov 1978	Riverflow was naturally diverted away from test area, so test may not be conclusive at this time
3.	Same as 2 but piles 9-ft spacing (dense)	300 300	49.2 11.0 6.4 66.6	164 222	164 222	Nov 1978	
1A)	24-in.-thick stone fill blanket on natural soil and stone berm in river	300 300	37.0 6.5 0.9 44.0	122 148	122 149	Jan 1980	Satisfactory performance
1B)	18-in.-thick stone fill blanket over 6-in. graded filter, fill and stone-filled trench	500 500	53.0 11.0 1.5 65.6	106 131	106 131	Jan 1980	Satisfactory performance
2.	Stone-fill dike parallel to bank and fill between dike and bank	250 250	23.0 5.5 0.7 29.2	91 117	91 117	Jan 1980	Stone dike performance satisfactory, but unprotected slope of fill between dike and bank is eroding
3.	Stone fill on natural bank with toe trench, except in front of existing timber wall	320 320	13.0 7.0 1.0 21.0	41 65	41 65	Jan 1980	Satisfactory performance
4.	Series of 7 stone-fill hard points spaced 100 ft on center, 20 to 40 ft long	600 20 to 40	55.0 13.0 1.8 69.8	90 116	1800* 2300*	Jan 1980	Hard points damaged by ice flows, some bank erosion between hard points * Based on avg 30-ft length.
5.	4.5-ft wide by 4.0-ft deep stone filled trench surrounded by filter fabric	200 200	8.0 4.3 0.6 12.9	38 65	38 65	Jan 1980	Satisfactory performance
1.	12-in. gabion mattress with filter fabric and vegetated upslope	500 500	47.5 2.9 3.3 53.7	95 107	95 107	Sep 1979	Overbank flood flow occurred in Oct 1981. Overall project performed well, but specific test panels were damaged to varying degrees. All upperbank vegetation held. Gabion mattress performed best, with no sign of damage.

(Sheet 1 of 7)

Exhibit XII-7

OTHER STREAMS NATIONWIDE (CONTINUED)

Map No.	Stream, Mile and Side, Local Vicinity, County	At or Near City, State, Cong. Dist., CE Office	Project Site Conditions: Riverbank (Geotechnical)	Flow (Hydraulic)	Erosion Agent
54	Connecticut R. (Continued)				
55	Connecticut R. 132.5 Left Northeast Utilities, Inc. Franklin	Northfield NH-2 New England MA	Material - 0-4 ft silty fine sand (SM); 4-10 ft sandy silt (ML); 10-25 ft silty fine sand (SM); 25-30 ft silty medfine sand. Height - 25 ft. Slope - range 1V on 1H to 1V on 2H	Velocity, normal <3 fps; high flow 4-6 fps; river slope, normal 0.1 ft/mile; high flow 0.5 ft/mile; site subject to wide fluctuations in water levels due to hydropower operations on river	Tractive force from velocity, ice, pool fluctuations, seepage, boat waves, overbank drainage
56	Delaware 13.6 miles D/S of Billingsport Gloucester	Paulsboro NJ-1 Philadelphia PA	Height - 20-30 ft. Slope - near vertical to flat, narrow beach at toe, medium to fine sand	Site in tidal portion of river; average 5.7-ft tidal range; current 3.4-4.2 fps	Wave action generated by passing vessels

	Types of Protection Tested	Lengths, ft, Bank, Structure	Total Costs, $/1000's, Contract, E&D, S&A, Total	Unit Cost $/ft of Length Contract and Total Bank	Structure	Date Constr.	Remarks and/or Conclusions
2A)	Stone-filled used tire matting, vegetated slope	250 250	13.6 0.8 1.0 15.4	54 61	54 61	Sep 1979	Stone-filled rubber tires held, but earth-filled tires failed to prevent loss of soil from bank
2B)	Earth-filled used tire matting, vegetated upslope	250 250	13.8 0.8 1.0 15.6	55 62	55 62	Sep 1979	
3.	Sand-and-cement-filled bags over filter fabric, vegetated upslope	500 500	50.0 3.0 3.5 56.5	100 113	100 113	Sep 1979	Sections of the sand-cement filled bags have slipped down the bank
4A)	B[illegible]d hay over filter f[illegible]ric, upslope v[illegible]getated	250 250	25.0 1.5 1.8 28.3	100 113	100 113	Sep 1979	Many of the hay bales have been washed away
4B)	Same as 4 but no filter	250 250	24.1 1.4 1.7 27.2	96 109	96 109	Sep 1979	
5.	No toe protection, vegetated upslope	500 500	22.2 1.3 1.6 25.1	44 50	44 50	Sep 1979	Severely eroded and bank receded [illegible]0 to 30 ft from original line
1.	Precast cellular concrete block mattress	600 600	119.7 7.2 8.4 135.3	200 225	200 225	Sep 1981	Project has not experienced significant flows
2.	Used tire wall with filter fabric	375 375	54.5 3.3 3.8 61.6	145 164	145 164		
3.	Used tire wall without filter fabric	375 375	41.0 2.4 2.9 46.3	109 124	109 124		
4.	Used tire mattress with filter fabric	350 350	62.1 3.7 4.4 70.2	178 201	178 201		
5.	Used tire mattress without filter	300 300	48.9 3.0 3.4 55.3	163 184	163 184		
	(All have vegetated upper slopes)						
1.	Pile-supported rubber tire wall, gravel-filled bulkhead with filter cloth	300 300	46.0 3.0 3.2 52.2	153 174	153 174	May 1980	E&A and S&A cost are estimated.
2.	Gabion mat with filter cloth	205 205	38.0 2.5 2.8 43.3	185 211	185 211	May 1980	
3.	Stone riprap; 18 in. on filter cloth	250 250	38.4 2.5 2.7 43.6	154 174	154 174	May 1980	
4.	Stone toe protection of existing bulkhead	270 270	24.4 2.0 2.1 28.5	90 106	90 106	May 1980	The cost for the stone toe protection does not include the cost of the existing bulkhead
5.	Nylon sandbags, dikes perpendicular to flow each 120 ft long, spaced 180 ft	460 360	43.4 2.0 2.1 47.5	99 103	126 132	May 1980	Bank revetment schemes successful, but tire bulkhead may require more maintenance
6.	Longard tube dikes 40 in. diameter, 125-ft long, spaced 200 ft with protective coating and filter cloth underlayment	740 500	37.0 2.0 2.1 41.1	50 56	74 82	May 1980	Sandbags and Longard tube dikes effective but vandalism caused extensive damage

(Sheet 2 of 7)

Exhibit XII-7

OTHER STREAMS NATIONWIDE (CONTINUED)

Map No.	Stream, Mile and Side, Local Vicinity, County	At or Near City, State, Cong. Dist., CE Office	Project Site Conditions: Riverbank (Geotechnical)	Project Site Conditions: Flow (Hydraulic)	Project Site Conditions: Erosion Agent
57	Green R. 26.5 Left Kent King	Kent WA-6 Seattle WA	Stratified fine sand and silt; typical bank. Height - 20 ft. Slope - near vertical to 1V on 1H	Average velocity 2-5 fps; peak estimated velocity 7 fps	Current velocity, piping
58	Kansas R. 43.0-44.0 Eudora Levenworth	Eudora KS-2 Kansas City KS	Height - 14-30 ft. Slope vertical to 1H on 1V. Stratified alluvium and glacial drift; silt and clay with lenses of sand	Average velocities 2-4.5 fps; river slope 1.7 ft/mile; site located on outside of bendway of meander	A 2-ft-thick layer of sand at normal water line becomes saturated on high water and pipes on drawdown, undermining the slope
59	Kanawha R. 52.3 Left South Charleston Kanawha	South Charleston WV-3 Huntington WV	Height - 30 ft. Slope - 1V on 1H; interbedded lenses of silt, clay, and sand	Peak average velocities 5.0 fps; river slope 0.8 ft/mile; occasional waves from wind and traffic 2 ft	Bank saturation from precipitation and high river stage followed by river drawdown; then piping of sand lenses in bank, undermining and sloughing; receding erodes slumped bank
60	Iowa R. 16.0 Right Wapello Louisa	Wapello IA-1 Rock Island IA	Height - 25-30 ft. Slope - vertical to 1V on 1H; clayey silt, over f-c sand, over stiff clay, over sand	Site located on outer side of 90-deg bend in river; velocities up to 6 or 7 fps at peak flows; river slope 1/7 ft/mile	Tractive erosion of stiff clay layer

	Types of Protection Tested	Lengths, ft, Bank, Structure	Total Costs, $/1000's, Contract, E&D, S&A, Total	Unit Cost $/ft of Length Contract and Total: Bank	Unit Cost $/ft of Length Contract and Total: Structure	Date Constr.	Remarks and/or Conclusions
1.	18-in. standard CE riprap with berm toe on 12-in. quarry spalls below ordinary high water line (OHW) sloped 1V on 2H; above the OHW - sloped 1V on 3H; two sections each of:					Oct 1980	Insufficient time to fully evaluate. Preliminary conclusions are: 1. Surface runoff from upland areas must be controlled 2. Wire mesh did not provide interim erosion protection needed for vegetal establishment 3. Native soil washed out of quarry spalls 4. Piping from drawdown or perched water table in coarse layers requires filter material design 5. Plant early in growing season 6. Presence of floating debris must be considered in design
	a. Native planting on natural bank	600 600	71.3 26.0 4.0 101.3	119 169	119 169	Oct 1980	
	b. Tied-down wire mesh with planting in mesh	600 600	80.9 26.0 4.0 110.9	135 185	135 185	Oct 1980	
	c. Mixture of 24-in.-thick quarry spalls and and soil with plantings	600 600	109.8 26.0 4.0 139.8	183 233	183 233	Oct 1980	
			Note: The above includes the cost of rock rib cutoffs between each section. These costs should be deducted to determine specific costs.				
1.	Windrow revetment of quarry-run stone placed at the following rates:					May 1979	A drought period followed construction and the project has not been tested to date
	a. 2.5 tons/ft	400 400	11.6 1.7 0.6 13.9	28 34	28 34	May 1979	
	b. 3.75 tons/ft	1200 1200	49.6 5.0 1.9 56.5	41 47	41 47	May 1979	
	c. 5.0 tons/ft	300 300	16.5 1.3 0.4 18.2	55 61	55 61	May 1979	
2.	Reinforced toe of quarry-run stone 5.75 tons/ft	600 600	24.9 1.7 0.6 27.2	42 45	42 45	May 1979	
1.	Slope regraded and protected with used tire mat	480 480	130.0 17.4 6.3 153.7	270 320	270 320	Dec 1979	All protection schemes performed satisfactorily with the floating tire breakwater. This scheme had problems with debris caught in structure, submerging it. Also, navigation hazard protective systems on the breakwater proved ineffective
2.	Soil-cement	300 300	95.0 10.8 3.9 109.7	315 365	315 365	Dec 1979	
3.	Floating tire breakwater	470 470	103.0 17.0 6.2 126.2	220 270	220 270	Dec 1979	
4.	Toe protection with 5-in. waste stone	300 300	141.0 10.8 3.9 155.7	470 520	470 520	Dec 1979	
1.	Permeable timber jetties extending into river; 100-ft spacing	600 432	60.5 3.6 4.8 68.9	101 115	140 159	Sep 1978	Timber jetties bent over by flow and lifted by river ice; jacks not effective in high-velocity flows and ice conditions. Jetties were repaired in fall, 1980, $18,100
2.	Grout-filled mat (Fabriform)	600 600	80.9 4.9 6.4 92.2	135 154	135 154	Aug 1978	

(Sheet 3 of 7)

Exhibit XII-7

OTHER STREAMS NATIONWIDE (CONTINUED)

Map No.	Stream, Mile and Side, Local Vicinity, County	At or Near City, State, Cong. Dist., CE Office	Project Site Conditions: Riverbank (Geotechnical)	Flow (Hydraulic)	Erosion Agent
60	Iowa R. (Continued)				
61	Little Miami R. Left Milford Clermont	Cincinnati OH-6 Louisville KY	Height - 75 ft. Slope - near vertical at top 30 ft, 1V on 1-1/2H lower slope. Sand and gravel over thin layers of fine sand and clay	Velocity - 2-5 fps normal to about 10 fps at peak flows; river slope 6.5 ft/mile; site on outside bend of river	Current velocity (tractive erosion) eroding toe of slope; outside of bend; seepage from abandoned sewers in upper bank
62	Lower Chippewa R. 21.0, 35.0, 46.0 Right 54.0, 22.0, 19.0, 15.0 Left Durand Pepin	Eau Claire WI-3 St. Paul MN	Thin layer of fine sand and silt over glacial outwash sands and gravel. Low sites: Height - 5-15 ft. Slope - vertical to 1V on 1H at base. High site: Height - over 100 ft	Velocity 1-5.5 fps at 18,100 DS; braided river slope 1.8 ft/mile	Bank saturation causes loss of soil strength and/or piping. Minor sloughs result which undermine upper bank; ice flows, waves

OTHER STREAMS NATIONWIDE (CONTINUED)

Types of Protection Tested	Lengths, ft, Bank, Structure	Total Costs, $/1000's, Contract, E&D, S&A, Total	Unit Cost $/ft of Length Contract and Total Bank	Unit Cost $/ft of Length Contract and Total Structure	Date Constr.	Remarks and/or Conclusions
3. Kellner jacks placed parallel to bank and laced with wire	1100 1100	81.6 5.0 6.5 93.1	74 85	74 85	Oct 1978	
1. Backfill (1V on 2H) placed behind a toe protection dike of:						Toe protection dike performing satisfactorily but upper slope is eroding
a. Riprap	300 300	103.0 29.0 2.0 134.0	345 450	345 450		
b. Gabions	200 200	84.5 19.0 1.5 105.0	425 515	425 515		
c. Concrete crib wall	500 500	260.5 48.0 3.5 312.0	520 625	520 625		Foundation construction for schemes tested is $278/LF and is included in the indicated costs
1. 5 sites tested:						
Site 1 low						
Sec 1: concrete block with filter cloth; block parallel and perpendicular to bank	400 400	22.2 3.5 0.4 26.1	56 65	56 65		Time insufficient for evaluation, but preliminary conclusions follow; appears satisfactory
Sec 2: same as Sec 1 but no filter cloth, rock toe provided	400 400	35.1 3.5 0.4 39.0	88 98	88 98		Appears satisfactory
Sec 3: dumped rock fill on natural bank	425 425	18.4 3.7 0.4 22.5	43 53	43 53		Appears satisfactory
Sec 4: dumped rock fill 18-in.-thick blanket	375 375	16.9 3.3 0.4 20.6	45 55	45 55		Appears satisfactory
Sec 5: same as Sec 4 but blanket thickness increased to 24 in. below control elevation water level	375 375	15.0 3.3 0.4 18.2	40 50	40 50		Appears satisfactory
2. Site 2 low						
Sec 1: filter fabric weighted with rock fill top and bottom, and some randomly placed between	400 400	18.2 3.5 0.4 22.1	45 55	45 55		Damaged by ice flows
Sec 2: Enkamat #7010 anchored top and bottom with rock fill and steel pin	225 225	15.5 2.0 0.2 17.7	69 79	69 79		Damaged by ice flows
Sec 3: Enkamat #7020, same as Sec 2	225 225	17.3 2.0 0.2 19.5	77 87	77 87		Damaged by ice flows
Sec 4: pile supported upright woven wire fence parallel to bank and brush placed between bank and fence	300 300	10.3 2.6 0.3 13.3	34 44	34 44		Damaged by ice flows
Sec 5: same as Sec 4 except provided with weighted wire fence toe protection	300 300	11.8 2.6 0.3 14.8	39 49	39 49		Damaged by ice flows

(Sheet 4 of 7)

Exhibit XII-[illegible]

OTHER STREAMS NATIONWIDE (CONTINUED)

Map No.	Stream, Mile and Side, Local Vicinity, County	At or Near City, State, Cong. Dist., CE Office	Project Site Conditions: Riverbank (Geotechnical)	Project Site Conditions: Flow (Hydraulic)	Project Site Conditions: Erosion Agent
62	Lower Chippewa R. (Continued)				
63	Pearl R. 3 sites both sides Monticello Lawrence	Monticello MS-3 Mobile AL	Silt and clay loam over layers of sand with occasional gravel	Sites 1 and 2 - located on outside of 135-deg river bend. Site 3 - just downstream of 90-deg bend	1. Direct current flow attack 2. Excess hydrostatic forces in slope with drawdown and slope slumping 3. Local drainage
64	Rio Chama R. 14.0 and 3.0 both sides Abiquiu and Chamita Rio Arriba	Espanola NM-1 Albuquerque NM	Silty sands loosely consolidated. Height - 5 ft upstream, 20 ft downstream	Site located on the outside of a 110-deg bend. Discharges controlled by Abiquiu Dam. Bank-full discharge 2000 cfs. Corresponding velocity 2.9 fps. Normal releases limited to about 1200 cfs. Longitudinal river slope 7.5 ft/mile	Direct current attack on bank-line materials causing removal of sands at the toe of the slope and sliding down of upper bank materials

	Types of Protection Tested	Lengths, ft, Bank, Structure	Total Costs, $ 1,000's, Contract, E&D, S&A, Total	Unit Cost $/ft of Length Contract and Total Bank	Unit Cost $/ft of Length Contract and Total Structure	Date Constr.	Remarks and/or Conclusions
	Sec 6: same as Sec 5 but on steeper bank	[illegible] [illegible]	[illegible] 2.? 3.3 13.?	33 43	33 43		Damaged by ice flows
	Sec 7: sandbag blanket on bank no steeper than 1V on 1H	300 300	14.5 2.6 0.3 17.5	48 58	48 58		Some damage by ice and weather
3.	Site 3 low						
	Sec 1: wood and wire fence pinned and weighted to bank at toe of slope	400 400	6.1 3.5 0.4 10.0	15 25	15 25		
	Sec 2: same as Sec 1 but on steeper slope	300 300	4.5 2.6 0.3 7.5	15 25	15 25		
	Sec 3: same as Sec 2 but with pile-supported woven wire fence and bush backfill between fence and bank	300 300	3.5 2.6 0.3 6.5	12 22	12 22		
	Sec 4: tree pendants angled downstream	600 600	5.? 5.3 0.6 11.2	9 19	9 19		
	Sec 5: tree pendants perpendicular to bank	640 640	3.5 5.6 0.7 9.8	5 15	5 15		
4.	Site 3 high Dumped rock fill. Quantities varied from 1/3 cu yd per linear foot to 2.5 cu yd per linear foot	1150 1150	66.5 10.1 1.2 77.8	58 68	58 68		Rock fill was dumped from top of bank. More than 75% remained on the slope well above area needed for protection. As erosion occurs, rock will fall into place
	Site 7 low Rock-filled hard points	2292 250	32.? 20.1 2.5 54.5	14 24	132 218		Appears satisfactory but some erosion between hard points
1.	Site 1: dumped rubble; 1V on 1H	400 400	109.5 40.3 2.4 152.3	274 331	274 381	Dec 1980	Insufficient monitoring time to develop conclusions
2.	Site 2: rubber tire mat banded together and anchored	400 400	63.7 40.3 2.4 106.5	159 266	159 266	Dec 1980	
3.	Site 3: concrete blocks anchored with steel pins and with a rock toe	200 200	71.6 20.2 2.4 94.3	358 471	358 471	Dec	
1.	Wire-mesh-lined log cribs filled with river-run cobbles	377 377	72.0 7.0 5.0 84.0	192 223	192 223	Mar 1981	Insufficient monitoring time to develop performance conclusions
2.	Gabion groins, 5 each, from 30-48 ft long. Sloped top downward toward river	230 226	21.0 3.0 3.0 27.0	91 93	119 119		
3.	Riprap revetment with 18-in.-thick section with thickened toe. Constructed of 4-12-in. river cobbles. Underlayer with gravel filter section and also a plastic filter cloth	279 279	44.0 3.0 2.0 49.0	156 176	156 176		

(Sheet 5 of 7)

Exhibit XII-7

OTHER STREAMS NATIONWIDE (CONTINUED)

Map No.	Stream, Mile and Side, Local Vicinity, County	At or Near City, State, Cong. Dist., CE Office	Project Site Conditions Riverbank (Geotechnical)	Flow (Hydraulic)	Erosion Agent
65	Roanoke R. (Continued)				
66	Sacramento R. 176.5 Right DS of Sidds Landing Glenn	Glenn CA-1 Sacramento CA	Alluvial sandy and silty clay with occasional layers of sandy gravel and silty gravel. Height ~ 20 ft. Slope - vertical to 1V on 2H	Located on meandering river; average velocity range 4-6 fps at 30,000 cfs to 8-11 fps at 160,000 cfs	Low flows erode toe; high flows saturate band and cause sloughing
67	White R. 259.7 Right Jacksonport Jackson	Jacksonport AR-1 Little Rock AR	Height ~ 20-25 ft. Slope - upper sloughed section nearly vertical. Materials consist of alluviums, fine sand, silt, and clay underlain by coarse sands and gravel	Test site located on onside of long river bend. Discharges controlled to some extent by upstream dams and powerhouses. No velocity measurement to date. River slope 0.3 ft/mile	Direct current attack on toe of slope cuts into bank-line materials. Loss of toe materials unstablizes upper bank materials which causes them to slough off into the river

	Types of Protection Tested	Lengths, ft, Bank, Structure	Total Costs, $/1000's, Contract, E&D, S&A, Total	Unit Cost $/ft of Length Contract and Total: Bank	Unit Cost $/ft of Length Contract and Total: Structure	Date Constr.	Remarks and/or Conclusions
1.	Stone rubble protection on bench cut into bank halfway upslope; vegetative treatment above bench, unprotected below bench	960 960	141.3 14.0 1.9 157.2	147 164	147 164	Mar 1981	No conclusions developed due to limited time to monitor
2.	Rubber tire mattress tied together and anchored with rock toe below water and vegetative cover on upper slope	532 532	88.0 14.0 1.9 104.0	166 195	166 195	Mar 1981	
3.	Rock windrow in excavated trench at top of slope	700 700	65.0 14.0 1.9 80.8	93 116	93 116	Mar 1981	
1.	Quarry rock toe protection 2 ft thick with upper slope vegetated	1000 1000	220.0 22.0 11.0	220 251	220 251	Oct 1981	No final conclusion developed as monitoring has not commenced
2.	Concrete pile groins (hard points) 20 ft long, spaced 30 ft on center along bank. Piles tied together on top - 17 units	500 340	380.0 47.0 23.0 450.0	760 900	1118 1324	Oct 1981	Preliminary conclusions: concrete pile hard points are expensive, requiring greater engineering effort and installation problems. High flows have exposed outer end of groins
	The test section consists of a continuous revetment with a full length toe riprap section and combinations of riprap and compacted clay sections on the 1-on-3 sloped upper banks. Specifics of the 13 different test sections are described:					Feb 1980	Adequate flows have not been experienced since completion of construction to adequately test the performance
1.	Heavy bermed toe section. Continuous upper bank riprap about 15 in. thick extending 11 ft above the toe section	940 940	106.2 15.1 13.6 134.9	113 144	113 144		
2.	Thick bermed toe section. Upper bank paved with alternate 20-ft-wide strips of compacted in situ clay material and then 15-in.-thick riprap all extending 8 ft above the toe section	80 80	10.3 1.4 1.3 13.0	129 163	129 163		
3.	Same as 2, except clay strips are widened to 40 ft	120 120	15.0 2.1 1.9 19.0	125 159	129 159		
4.	Same as 2, except clay strips are widened to 60 ft	160 160	19.6 2.8 2.5 24.9	123 156	123 156		
5.	Same as 2, except clay strips are widened to 80 ft	200 200	24.2 3.5 3.1 30.8	121 154	121 154		
6.	Same shape as 2, but continuous clay section	470 470	42.6 6.0 5.5 54.1	91 115	91 115		

(Sheet 6 of 7)

Exhibit XII-7

OTHER STREAMS NATIONWIDE (CONTINUED)

Map No.	Stream, Mile and Side, Local Vicinity, County	At or Near City, State, Cong. Dist., CE Office	Project Site Conditions: Riverbank (Geotechnical)	Flow (Hydraulic)	Erosion Agent
67	White R. (Continued)				
68	White R. 143.0 Right Des Arc Praire	Des Arc AR-2 Memphis TN	Silty clay (loess) over desiccated, jointed, very stiff clay, over inter-bedded layers of silt and clay over fine sand. Height - 35-40 ft. Slope - vertical to 1V on 6.6H at base	Velocity 1-5 fps; stream slope 1/3 ft/mile	During high river stage, water infiltrates into stress relief cracks on bank face, causing loss of shear strength and excess hydro-static pressure on drawdown. Liquefaction may also occur

	Types of Protection Tested	Lengths, ft, Bank, Structure	Total Costs, $/1000's, Contract, E&D, S&A, Total	Unit Cost $/ft of Length Contract and Total: Bank	Unit Cost $/ft of Length Contract and Total: Structure	Date Constr.	Remarks and/or Conclusions
7.	Same as 6, only uncompacted in situ clay	470 470	41.2 5.8 5.3 52.3	88 111	88 111		
8.	Thin toe section without berm extending 2 ft higher up the slope than the upstream bermed toe sections. Upper bank paved with alternate 20-ft-wide strips of placed 15-in.-thick compacted clay material and 15-in.-thick riprap. All strips extend 3 ft above the toe section	80 80	5.1 0.7 0.7 6.5	64 81	64 81		
9.	Same as 8, only clay strips are widened to 40 ft	120 120	7.6 1.1 1.0 9.7	63 81	63 81		
10.	Same as 8, only clay strips are widened to 60 ft	160 160	10.2 1.4 1.3 12.9	64 81	64 81		
11.	Same as 8, only clay strips are widened to 80 ft	200 200	12.7 1.8 1.6 16.1	64 81	64 81		
12.	Same shape as 8, but continuous clay section	540 540	44.4 6.3 5.7 56.4	82 104	82 104		
13.	Same as section 1	300 300	33.9 4.8 4.3 43.0	113 144	113 144		
1.	Rock toe stability key at base of slope with upper slope of:					May 1980	Cracks developed in grout-filled fabric mat soon after completion due to subsurface movements. Stone key may have been constructed too coarse or too shallow
	a. 4-in.-thick grout-filled mat (Fabriform)	333 333	165.7 29.4 20.4 215.5	498 647	498 647		
	b. Used tire mat fill with soil and plantings	333 333	177.8 29.4 20.4 227.6	533 683	533 683	May 1980	
	c. 6-in.-thick soil-cement paving	333 333	164.5 29.4 20.4 214.3	493 643	493 643	May 1980	

PART XIII: EVALUATION OF EXISTING PROJECTS

A variety of existing streambank works (built before or separate from the Streambank Erosion Control Evaluation and Demonstration Act of 1974) at 50 projects throughout the United States were selected for limited observation, monitoring, and evaluation using previous field observations and data and information acquired during the Section 32 Program. These existing projects were chosen to represent a wide variety of streams, soils, and bank protection techniques. Evaluation of these existing projects allowed determination of which protection types had experienced either good or bad performance. The findings supplement the evaluations of the demonstration projects constructed under the Section 32 Program. See Exhibit XIII-1 for locations of the existing projects. A detailed report on these projects is given in Appendix H and a summary of information on each project is given in Exhibit XIII-5.

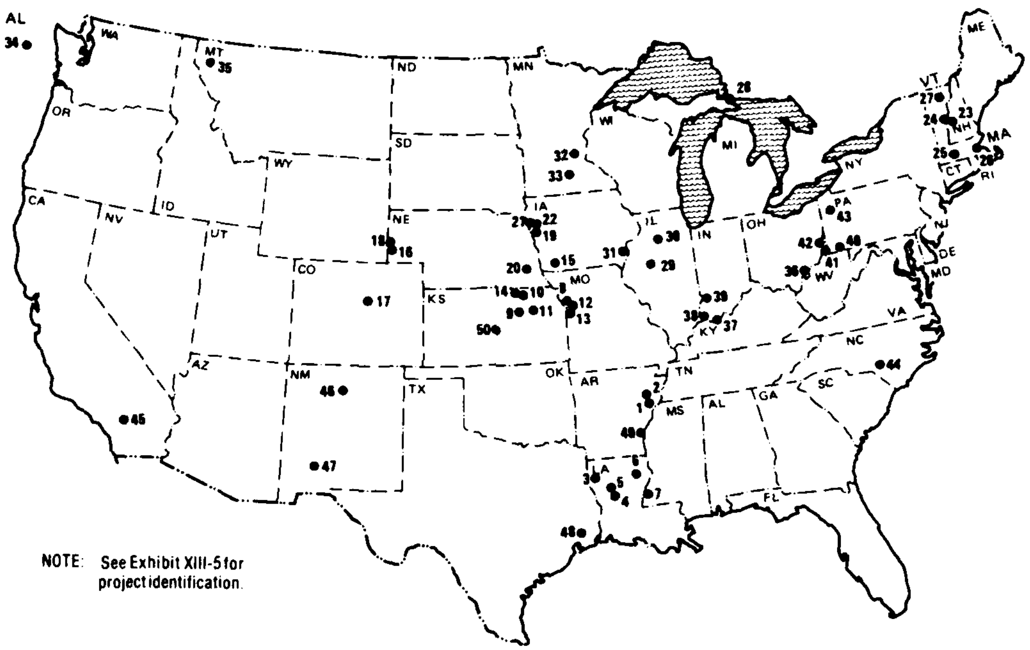


Exhibit XIII-1. Locations of existing projects

CHANNEL CHARACTERISTICS AND EROSION PROBLEMS

Summary and Range of Streambank (Geotechnical) and Flow (Hydraulic) Characteristics

The streambanks and beds of the 50 existing projects vary from homogeneous clays, sands, silty sands, or gravels to various heterogeneous soil compositions. Bank slopes varied from near vertical to 1-vertical-on-5-horizontal with bank heights ranging from about 4 to 40 ft. Groundwater levels, channel bed gradients, and streamflows are generally representative of most small to medium streams in the United States. Discharges and velocities range from 0 to

865,000 cfs and 0 to 12 fps, respectively. Available details for each of the 50 projects are provided in Appendix H.

Causes of Erosion and Failures

The major causes of bank erosion that required design and construction of the existing projects were:

- Channel bed degradation
- Streamflow
- Water-level fluctuations
- Wave action

High stage streamflow in the various channel alignments and river stages were considered to be the most frequent causes of subsequent erosion and failure observed at nine of the existing projects that have experienced any damage. Six of these nine projects were flanked during high stage streamflow. Channel bed degradation was the most significant failure mechanism necessitating these 50 projects as shown in Exhibit XIII-5. Multiple causes were identified at many projects including a combination of the four causes listed above and other less frequent causes such as overbank flow, seepage, ice debris, and freeze thaw.

TYPES OF PROTECTION AT EXISTING PROJECTS

General Description

A general physical description of the protection methods used on the 50 existing projects is given in Exhibit XIII-5.

Relative Costs

Cost data for most of the existing projects were not comparative due to the wide variation in the construction years (1939-1977).

MONITORING AND OBSERVATIONS OF EXISTING PROJECTS

Monitoring of the existing projects after collection of available data consisted of field inspections and evaluations. Many of the existing projects were of advantage to the program because they had experienced several flood flows. Historical discharge data and past performance were collected for each existing project.

MAINTENANCE AND REHABILITATION OF EXISTING PROJECTS

Rehabilitation or maintenance of existing projects was not required under the Section 32 Program.

SUMMARY OF FINDINGS

A wide range of geologic and hydraulic conditions, failure mechanisms, and protection techniques are represented by the 50 existing sites located throughout the Nation. The evaluation of these existing sites added significantly to the overall Section 32 Program

evaluation because of the variety of conditions and the longer time period that the existing sites have experienced flow.

Significant Observations

- The Winooski River project, Vermont, constructed by the Soil Conservation Service (SCS) in the late 1930's at the request of local landowners and monitored last in 1980 by the New York District, Corps of Engineers, is perhaps the most unique of the 50 projects because of the large watershed (1,065 square miles), the length of time since project construction (40 yr), and the general success of erosion control. The two sites observed, where the temporary stone-filled log cribbing and hand-placed riprap structures were constructed, indicated no sign of erosion on the streambanks with various types of vegetation providing good bank coverage above the normal water surface. Additional details and findings are contained in Appendix H.
- Used tires filled with gravel were used successfully by private residents at four existing projects (two shown in Exhibit XIII-2). These projects were highly cost-effective due to landowners collecting free materials and doing the work themselves.

Connecticut River at Thetford, VT

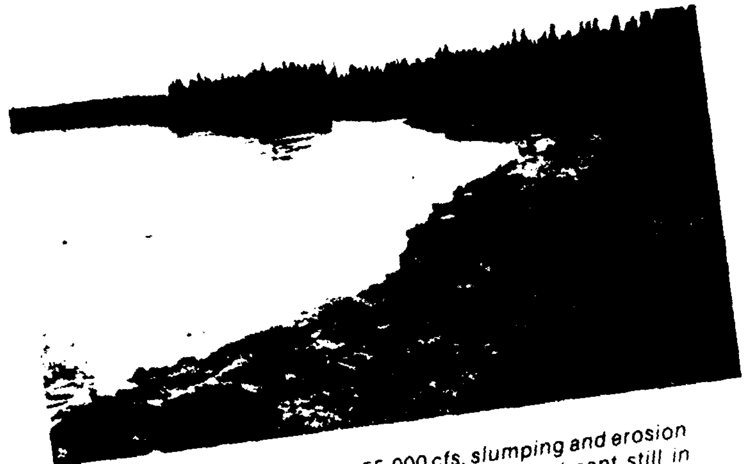
Monongahela River (left bank) near California, PA

Exhibit XIII-2. Stone-filled tire revetment constructed by property owners (successful)

- Rock and sheet-pile grade-control structures were effective in the prevention of channel bed degradation for low structures. Gabions were also used at one project for grade control.
- Vegetation has been successfully used on upper banks in conjunction with structural protection on the lower bank.
- Gabions were effective in establishing a low-flow channel with vegetated upper banks.
- Manufactured blocks, slabs, etc., for bank protection had a higher failure rate than the more conventional rock-type bank protection.
- Permeable spur dikes constructed of board fence anchored to steel piling were unsuccessful at two existing projects due to flanking during high stage streamflows.
- Soil-cement was used to form riprap on one existing project. Site-specific testing on this procedure is needed to determine application and curing rates.
- Kellner jacks were successfully used at four existing projects. Proper installation (alignment, anchoring, and spacing) is required and some maintenance is common.
- Wire fence retards were used successfully on several existing projects. The fence promotes sediment deposition and growth of vegetation along the channel side slopes. Proper fencing design requires toe protection to prevent undermining and has proved cost-effective on many small streams.
- Ice revetment was a new concept tried on the Tanana River in Alaska with unsuccessful results (Exhibit XIII-3).

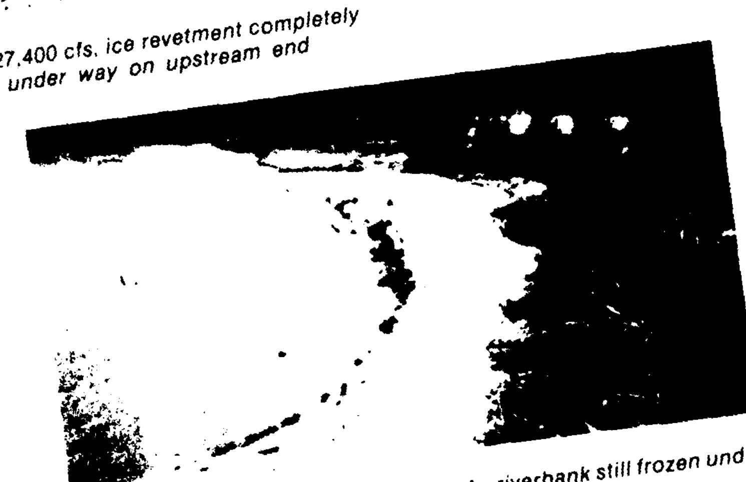
Conclusions

- The most cost-effective means observed for protecting streambanks against erosion was where landowners on smaller rivers used locally available materials (used tires filled with cobbles) and did the work themselves.
- Rock is the most commonly used material for protection against streambank erosion, although the methods of placement and design vary widely. Thirty-two of the fifty existing projects incorporate some type of stone ranging from total riprap revetment (e.g., quarry-run or graded stone blankets; see Exhibit XIII-4), to trench-fill longitudinal toe protection, grade-control structures, stone-filled fences, stone-covered lumber mats, timber cribs filled with stone, used tires filled with stone, pile dikes with stone fill, gabion mats, and stone dikes. All of these methods have provided protection ranging from poor to excellent, with the majority being rated as good. The project rated fair required repairs due to partial failure.
- Riprap revetment was the first choice of bank protection, where stones of sufficient size were available, because of durability and other advantages.
- A riprap revetment is flexible and is neither impaired nor weakened by slight movement of the bank resulting from settlement or other minor adjustments.
- Local damage or loss of rock is easily repaired by the placement of more rock.
- Construction using rock is not usually complicated and no special equipment or construction practices are necessary.
- Riprap is recoverable and may be stockpiled for future use.
- Quarry-run stone is usually more cost-effective for long-term protection than other protection types.



5 May 1979, discharge is 55,000 cfs, slumping and erosion of riverbank on downstream end, ice revetment still in place on upstream end

12 May 1979, river discharge is 27,400 cfs, ice revetment completely melted, riverbank erosion under way on upstream end



4 June 1979, river discharge is 30,200 cfs, riverbank still frozen under sawdust, erosion progressing rapidly

Exhibit XIII-3. Ice revetment, Tanana River, Alaska (failure)

Exhibit XIII-4. Ohio River (left bank) at Cloverport, Kentucky. Downstream view shows toe of revetment under wave attack due to passing barge traffic (19 June 1978). Typical riprap revetment constructed by the Corps of Engineers (successful)

SIGNIFICANT PARTICIPATION BY OTHER ORGANIZATIONS

The 50 existing projects were constructed by the Soil Conservation Service, private interests, and U. S. Army Corps of Engineer Districts as indicated in Exhibit XIII-5. Design, construction, and performance data for the existing projects were obtained from these agencies. Historical flow data for many of the projects were obtained from the U. S. Geological Survey.

Exhibit XIII-5

SUMMARY OF EXISTING BANK STABILIZATION PROJECTS

Map No.*	Stream Project Location CE Office Year Completed	Erosion Agent	Protection Method	Present Condition and Remarks
1	St. Francis River Clarks Corner, AR Memphis 1964	Eddy currents set up around bridge pier	Stone riprap on lumber mattress (lower bank) and riprap on filter fabric (upper bank)	Excellent. Bridge abutment endangered by scour pocket which cut into roadway on downstream side of bridge
2	Caney Creek Caney Creek, AR Memphis 1975	Streamflow over highly erodible bank soils	Lime and gypsum treatment, clay gravel lining, vegetation	Excellent. Test channel in dispersive clay; project constructed by SCS
3	Red River Morameal, LA New Orleans 1975	High stage streamflow against concave bank of bendway	Local and specified stone, sand-filled bags, soil-cement blocks, gabions, and cellular block on upper bank	Very good. Protect levee and reduce bank erosion. Only high water in April 1979
4	Red River Fausse, LA New Orleans 1975	High stage streamflow against concave bank of bendway	Trench-fill and pile revetment, pile dikes w/stone fill	Excellent. Reduce bank erosion and maintain channel alignment
5	Red River Perot, LA New Orleans 1970	High stage streamflow against concave bank of bendway	Permeable timber fence dikes	Upstream end of dike field lost. Protects pipeline crossing; 5-year design life; major repair and upstream extension required in 1978
6	Big Creek Big Creek, LA Vicksburg 1977	Channel realignment resulted in a steeper bed gradient and higher flow velocities; grade control was necessary to prevent bed degradation and bank failure	Sheet-pile weir structures with stone riprap upstream and downstream of pilings	Good. Part of channel enlargement project
7	St. Catherine Creek Natchez, MS Vicksburg 1973	High stage streamflow against concave bank of bendway	Local materials, tires, and timber piles	Good. Bank protection constructed by local resident
8	Little Blue River Independence, MO Kansas City 1978	Streamflow over highly erodible bank soils	Riprap on side slopes of low-flow channel with short horizontal blanket at toe	Excellent. Protects side slopes of low-flow channel
9	Republican River Milford Dam, KS Kansas City 1969	Streamflow over highly erodible soils	Stone riprap revetment with horizontal toe blankets; four test sections, with various toe configurations	Very good. Site located on outlet channel of Milford Dam
10	Little Timber Creek Frankfort, KS Kansas City 1963	Channel realignment resulted in a steeper bed gradient and higher flow velocities; grade control was necessary to prevent bed degradation and bank failure	Series of sheet piling and rock sills	Good. Structures prevent channel degradation and subsequent damage to adjacent levees

(Continued)

* See Exhibit VIII-1 for project locations.

(Sheet 1 of 5)

Exhibit XIII-5 (Continued)

Map No.	Stream Project Location CE Office Year Completed	Erosion Agent	Protection Method	Present Condition and Remarks
11	Mud Creek Lawrence, KS Kansas City 1978	Channel realignment would result in a steeper bed gradient and higher flow velocities; grade control was necessary to prevent bed degradation and bank failure	Four sheet piling and rock sills	Excellent. Structures prevent channel degradation
12	Little Blue River Independence, MO Kansas City 1978	Channel realignment would result in a steeper bed gradient and higher flow velocities; grade control was necessary to prevent bed degradation and bank failure	Sheet piling and rock sills in low-flow channel	Excellent. Structures prevent degradation of low-flow channel
13	Little Blue River Independence, MO Kansas City 1978	Streamflow over highly erodible soil	Noncohesive materials replaced by seeded clay blanket	Good. Protects high-flow channel berm and side slopes
14	Big Blue River Near Marysville, KS Kansas City 1977	High stage streamflow against concave bank of bendway	Fencing with rock-dike tiebacks	Severe damage to fencing. Structure placed to protect county road and right abutment of bridge
15	102 River Bedford, IA Kansas City 1974	High stage streamflow through relatively straight reaches and channel bed degradation	Fabriform mat	Failed. Protection of bridge abutment, dam abutment, and bank. Undercutting of mat led to failures
16	Gering Drain Near Gering, NE Omaha 1969	Streamflow resulting in channel degradation and flow over highly erodible bank soil	Double-row fencing filled with stone or hay bales	Very good. Fencing is part of plan to prevent rapid enlargement or drains
17	Plum Creek Near Denver, CO Omaha 1970	High stage streamflow against concave bank of bendway	Woven wire fencing on steel rail post, stone root, and four perpendicular stone dikes	Excellent. Protects waterline crossing
18	Gering Drain Gering, NE Omaha 1969	See erosion agent under Site 16	Several low broad-crested rock sills	Very good. Sills are part of plan to prevent rapid enlargement of drains
19	Little Sioux River Onawa, IA Omaha 1969	Overbank flow	Gabion mattresses	Fair. Protection of stilling basin side slopes when high flows bypass drop structure and reenter channel as overbank flow
20	Deadman's Run and Antelope Creek Lincoln, NE Omaha 1979	Channel realignment resulted in a steeper bed gradient and higher flow velocities; grade control was necessary to prevent bed degradation and bank failure	Gabion baskets along base of side slopes with grass seeding on upper bank; gabion drop structures	Excellent. Channel was realigned to accommodate urban development

(Continued) (Sheet 2 of 5)

Map No.	Stream Project Location CE Office Year Completed	Erosion Agent	Protection Method	Present Condition and Remarks
21	Floyd River Sioux City, IA Omaha 1966	Channel realignment would result in a steeper bed gradient and higher flow velocities; grade control was necessary to prevent bed degradation and bank failure	Sheet piling and rock sills (design based on extensive model tests at the University of Iowa by CE personnel)	Very good. Channel relocated
22	West Fork Ditch Onawa, IA Omaha 1972	Channel realignment resulted in a steeper bed slope and higher flow velocities; grade control was necessary to prevent bed degradation and bank failure	Low rock sills in channel bottom; repairs (based on limited model studies at Mead Hydraulic Laboratory) consisted of creating positive sheet-pile crest and short length of rock toe	Good. Extensive erosion during high flows of 1973; no damage thereafter
23	Connecticut River Hanover, NH New England 1962	High stage streamflow through relatively straight reach, water-level fluctuation, freeze-thaw, ice action, and boat wake waves	Stone riprap revetment	Very good. Property is owned by Dartmouth University. Revetment constructed by New England Power Company
24	Connecticut River Thetford, VT New England 1972	High stage streamflow through relatively straight reach, water-level fluctuation, freeze-thaw, ice action, and boat wake waves	Used-tire bulkhead	Very good. Constructed by local resident
25	Connecticut River Turners Falls Pool, MA New England 1977	Water-level fluctuation, freeze-thaw, ice action, high stage flow, and boat wake waves	Tree removal, hydroseeding with and without riprap toe protection	Very good with toe protection, poor without. Nine miles of river bank protected by Northeast Utilities; project has not been tested by high flow
26	Hayward Creek Quincy, MA New England 1977	High stage streamflow through relatively straight reach and overbank flow	Paving block (Monoslab)	Very good. Some minor settling from overbank flow in 1978
27	Winooski River North Williston, VT New York Late 1930's	High stage streamflow against concave bank of bendway, ice action, debris	Stone riprap revetment and rock-filled log cribbing	Good. Poplar log cribs rotted in 4 years; stone and vegetation providing good protection
28	St. Marys River Mission Point, MI Detroit 1974	Wave action	Stone riprap revetment	Excellent. Protects bank of recreational island
29	Illinois Waterway Banner Levee, IL Rock Island 1976	Wave action	Stone riprap revetment	Excellent. Protects farmland behind levee
30	Bureau Creek Bureau County, IL Rock Island 1974	High stage streamflow against concave bank of bendway	Kellner jacks	Fair. Protects levee of I&M Canal; jacks failing

(Continued)

(Sheet 3 of 5)

Exhibit XIII-5 (Continued)

Map No.	Stream Project Location CE Office Year Completed	Erosion Agent	Protection Method	Present Condition and Remarks
31	Iowa River Louisa County, IA Rock Island 1976	High stage streamflow through relatively straight reach	Timber spur jetties	Failed. Protected pipeline; failed due to flanking
32	Minnesota River Savage, MN St. Paul 1966	High stage streamflow against concave bank of bendway and water-level fluctuations caused by passing commercial vessels	Quarry-run stone	Very good. Minor erosion also due to seepage and frost action
33	Minnesota River Mankato, MN St. Paul 1971/79	High stage flow through relative straight reach	Stone riprap revetment of two gradations	Very good. Comparison of quarry-run with well-graded stone
34	Tanana River Fairbanks, AK Alaska 1977/78	Ice action and high stage streamflow through relatively straight reach	Tree revetment, timber mattress, ice revetment	Failed. Failure has occurred on sections of all three methods
35	Fisher River Libby, MT Seattle 1967	Channel realignment resulted in a steeper bed slope and higher flow velocities; grade control was necessary to prevent bed degradation and bank failure	Grade-control structures with stone riprap revetment on side slopes	Good. Channel realignment was necessary to accommodate relocated railroad main line
36	Hocking River Athens, OH Huntington 1971	Channel realignment required side-slope protection, and overbank drainage control	Gravel blanket, stone riprap revetment, crown vetch, drainage interceptor system	Very good. To stabilize channel relocation project in the Hocking River floodplain
37	Ohio River Cloverport, KY Louisville 1973	Seepage, water-level fluctuations, wave action	Stone riprap revetment	Very good. Protects highway
38	Ohio River Newburgh, IN Louisville 1976	High stage streamflow against concave bank of bendway, wave action, seepage	Stone riprap revetment	Very good. 6200 ft of bank protection
39	White River Levee Unit 8, Edwardsport, IN Louisville 1975	High stage flow against concave bank of bendway	Channel cutoff	Good. To protect agricultural levees constructed in 1940
40	Monongahela River California, PA Pittsburgh 1977	High stage streamflow through relatively straight reach, drawdown effect from high water	Coarse-rock-filled used-tire bulkhead	Good. 90 ft of bank protection by local resident
41	Ohio River Wheeling, WV Pittsburgh 1971	High stage streamflow through relatively straight reach; drawdown effects, overbank drainage	Stone riprap revetment on filter fabric	Good. Bank protection at municipal parking garage. Some repair required
42	Ohio River Tiltonsville, OH Pittsburgh 1968	High stage streamflow through relatively straight reach; overbank drainage	Gravel blanket (3/8- to 4-1/2-in. aggregate, no bedding)	Very good. 2600 ft of bank protection

(Continued)

(Sheet 4 of 5)

Exhibit XIII-5 (Concluded)

Map No.	Stream Project Location CE Office Year Completed	Erosion Agent	Protection Method	Present Condition and Remarks
43	Woodcock Creek Saegertown, PA Pittsburgh 1973	High stage streamflow against concave bank of bendway	Gabion spurs	Good. Experienced some damage
44	Little Rockfish Creek Hope Mills, NC South Atlantic 1976	High stage flow against concave bank of bendway; seepage	Gabions and vegetation	Good. 20 lin ft of gabions slipped 6-8 ft vertically due to groundwater seepage; repaired with crushed stone and timber toe
45	Mill Creek Mill Creek Levee, CA Los Angeles 1970	High stage streamflow against concave bank of floodway	Gabion midfloodway barrier	Very good Extremely high velocity and heavy debri.
46	Rio Grande River Espanola, NM Albuquerque 1951	High stage streamflow through a relatively straight reach	Kellner jacks, trees	Very good. Minor repairs, protects irrigation canal
47	Cuchillo Negro Creek Truth or Consequences, NM Albuquerque 1977	Streamflow over highly erodible bank soil	Gabion spur dikes and revetment	Very good. Levee protection
48	Trinity River Moss Hill, TX Galveston 1966	High stage streamflow against concave bank of bendway	Timber fence dikes	Good. Protects bridge abutment
49	Arkansas River Merrisach Lake, AR Little Rock 1972	Wave action	Timber pile wall	Very good. In 1980 about 10 percent of wall required some repair to cap boards
50	Arkansas River Ellinwood, KS Tulsa 1974	High stage streamflow against concave bank of bendway	Kellner Jack Fields at four sites	Excellent. Project exposed to major flood in June 1981

(Sheet 5 of 5)

PART XIV: PERFORMANCE OF PROTECTION METHODS AND TECHNIQUES

A wide range of geotechnical and hydraulic conditions, failure mechanisms, protection techniques, and materials are represented among the 68 demonstration and 50 existing projects. Substantial emphasis was placed on local availability of materials, simple constructibility, and economy. Many of the projects constructed under the Section 32 Program have not experienced critical streamflow events to permit an assessment of their behavior and effectiveness. Therefore, some evaluations presented in this report are preliminary and site-specific. The evaluation of existing projects, though not nearly as detailed as for the demonstration projects, greatly enhanced the Section 32 Program because of the variety of stream parameters and the longer time period that most of the existing projects have been exposed to natural field conditions. The performance and findings to date on the various protection methods used in each of the demonstration and existing projects are summarized in the following sections of this Part and in Exhibit XIV-1.

The streambank protection performance relative to the cause of erosion and/or failure given in Exhibit XIV-1 was derived from the individual reports on each demonstration and existing project (Appendices D-H). The performance of each project is listed in Exhibit VIII-1 and the types of erosion and/or failure are described in PART VII. Many of these performance observations as of summer 1981 are of a preliminary nature, and general conclusions should not be drawn without reviewing the specific details of each item. However, a predominance of good performance indicators (PA's) over failure indicators (F's) in any given block of Exhibit XIV-1 should be at least a tentative indication of a successful protection method for that cause of erosion and/or failure. Many of the blocks have no entries, either because the type of protection has no relation to the cause of erosion and/or failure or because the various project site conditions were such that testing all pertinent types of protection for all causes of erosion and/or failure was not possible.

The following comments (costs and findings) on the various methods evaluated to date are listed according to their functional use for (1) streambank surface protection, (2) bank mass stability, or (3) overall channel (or flow) stabilization. (See column headings in Exhibit XIV-1 and line headings in Exhibit VIII-1.) The reported cost data (approximate 1981 dollars per linear foot of bank line protected) include material, equipment, and labor costs of actual construction plus 10 to 60 percent additional for engineering, design, supervision, and administration. These demonstration project costs are for small amounts of specially designed bank protection constructed by general contractors. Many protection methods presented are readily adaptable to self-help construction. In situations where property owners can provide their own labor and equipment, construction costs would be significantly reduced. However, the shorter life expectancy and higher maintenance costs of many of these techniques also must be considered. Specific projects, as appropriate, are identified by a group symbol and map number relating to project lists and maps in preceding parts of this report and in the appendices where additional details are given: O - Ohio River; M - Missouri River; Y - Yazoo River Basin; N - Other Streams, Nationwide; E - Existing Projects; and L - Laboratory (G - Geotechnical, H - Hydraulic, BB - Big Black River, and DC - Durden Creek). For example, "M-15" would refer to a Missouri River demonstration project identified by map number 15 (Ionia Bend).

Exhibit XIV-1

Streambank Protection Performance Relative to Causes of Erosion and/or Failure

Section 32 Program Demonstration and Existing Projects - As of Summer 1981

CAUSE OF EROSION AND/OR FAILURE		TYPES OF PROTECTION Streambank Surface Protection Upper and Middle Bank Monolithic Cover (Low Porosity)	Loose Material Cover (Porous)	Matting Cover (Porous)	Bulkhead	Vegetation
Streamflow	Streamflow over Highly Erodible Soils	E(PA)-2 E(F2)-13	E(PA)-9			E(PA)-2
Streamflow	High-Stage Streamflow Against Concave Bank of Channel Bend	D(PA)-59 D(F2)-38,43 D(F3)-67 D(FA)-9	D(CN)-17,25,32,64 D(PA)-9,10,13,14 29,31,34,36 59,62,63,67 E(PA)-1,38	D(PA)-9,43,59,63 D(F1)-62 D(F2)-38 D(F3)-57 E(F1)-7		D(CN)-17,25,50 D(PA)-10,31,34,36 54,59,62,67 D(F2)-38 E(PA)-36 E(F4)-44
Streamflow	High-Stage Streamflow Through a Relatively Straight Reach	E(F2)-15 E(FA)-34	D(CN)-11,16,21,23 26,27,28,33 37 D(PA)-8,12,15,30 31,35,53 E(PA)-26,33,42 E(F4)-41	E(F1)-34		D(CN)-11,16,19,23 26,27,33,37 55 D(PA)-15,19,20,22 30 D(F1)-8 E(PA)-20,36
Water-Surface Displacement	Wave Action	D(FA)-9	D(PA)-9	D(PA)-9		D(CN)-50
Water-Surface Displacement	Water-Level Fluctuations		E(F4)-41	D(CN)-55		D(CN)-55,65
Water-Surface Displacement	Sloughing on a Falling Stage	D(PA)-59,68 D(F1)-68 D(FA)-9	D(PA)-1,2,3,5,9 53,59,68 D(F2)-6 D(F4)-7	D(CN)-4 D(PA)-3,9,59,68 D(F2)-6	D(CN)-4 D(PA)-3 D(F1)-5 D(F2)-1 D(F4)-5	D(CN)-66 D(PA)-3,59,68 D(F1)-1,2 D(F4)-7
Channel Bed Degradation	Change of Channel Alignment or Flow, Causing Increased Slope and Velocity					
Water Flow over and Through Bank	Overbank Drainage		E(PA)-42 E(F4)-41			E(PA)-36 with drain system
Water Flow over and Through Bank	Piping	D(PA)-59	D(PA)-1,2,3,5,53,59 D(F2)-6 D(F4)-7	D(CN)-4 D(PA)-3,59 D(F2)-6	D(CN)-4 D(PA)-3 D(F1)-5 D(F2)-1 D(F4)-5	D(PA)-3,5,59 D(F1)-1,2 D(F4)-7
Water Flow over and Through Bank	Seepage		E(PA)-37,38			
Temperature & Debris Action	Freeze-Thaw Cycle					
Temperature & Debris Action	Ice and Debris Attack		D(PA)-53,62	D(F2)-62 E(F1)-34		D(CN)-50 D(PA)-62

Notation: E(PA)-2
- Map Number of Project (See Exhibits III-2 and XIII-5)
- Performance Code (as of Summer 1981)
- Existing or Demonstration Project

Performance Code (Same as Exhibit VIII-1):
- CN - Project completed but not tested under design flow conditions
- PA - Project performing as-designed

Exhibit XIV-1

TYPES OF PROTECTION (Continued)							
Streambank Surface Protection (Continued)					Stream Stabilization or Modification		
Lower Bank and Toe					Grade Control of Channel Bottom	Hold or Modify Flow Alignment	
Monolithic Cover (Low Porosity)	Loose Material Cover (Porous)	Matting Cover (Porous)	Bulkhead	Vegetation	Sheet Piling and Rock Sill	Control Parallel to Eroding Bank	Control Protruding from Bank
E(PA)-2	D(CN)-66 E(PA)-8,9	E(PA)-47		E(PA)-2		E(PA)-16	D(CN)-66 E(PA)-47
D(PA)-60 D(F1)-54 D(F2)-38,43	D(CN)-17,25,32 50,64 D(PA)-10,13,14 29,31,34 35,36,57 58,61,62 63,67 D(F2)-14 D(F4)-29,51 E(PA)-1,3,4,27 36,35,38 E(F1)-32	D(PA)-43,62 D(F1)-62 D(F2)-38 E(PA)-1,3 E(F1)-7 E(F4)-44	D(PA)-61	D(PA)-52 D(FA)-29		D(CN)-64 D(PA)-38,39,43 52,62 D(F1)-40,62 D(F2)-38,41,42 D(F4)-51,60 D(PA)-43 E(CN)-50 E(PA)-17 E(F1)-14,30 E(F4)-45 E(FA)-27	D(CN)-32,49,64 D(PA)-10,13,34 36,38,39 43,51,62 D(F2)-38,41,59 D(F4)-29,60 E(PA)-14,17 E(F2)-43,48 E(F4)-5 Channel Relocation E(PA)-39
E(F2)-15	D(CN)-11,16,18 21,23,26 27,28,33 37 D(PA)-12,15,19 20,22,30 35 E(PA)-23,26,33 35,36	D(CN)-55 E(PA)-20 E(F1)-34	D(CN)-55 E(PA)-24 40	E(PA)-46		D(PA)-53 E(F4)-46	D(CN)-11,18,24 33,37 D(PA)-12,15,19 20,22,30 35 D(F2)-53 E(FA)-31
	D(CN)-50 D(PA)-56 E(PA)-23,25,28 29,37,38	D(PA)-56	D(PA)-56 E(PA)-24 E(F4)-49	E(F2)-25			D(F1)-56
	D(CN)-65 E(PA)-23,25,37 E(F1)-32	D(CN)-55,65	D(CN)-55 E(PA)-24 40	D(CN)-55 E(F2)-25			
	D(CN)-66 D(PA)-68					D(F2)-5	D(CN)-4
					D(CN)-46 D(PA)-44,45 47,48 E(PA)-11,12 18* E(F1)-35* E(F2)-21 E(F4)-6,10 22 Gabion: E(PA)-20		
		E(F2)-19					
	E(PA)-37,48	E(F4)-44					
	E(PA)-23,25		E(PA)-24	E(F2)-25			
	D(CN)-50 D(PA)-62 D(F4)-51 E(PA)-23,25,27	D(PA)-62 D(F2)-62 E(F1)-34	E(PA)-24	D(PA)-62 E(F2)-25	*Rock sill only	D(PA)-62 D(F1)-62 D(F4)-51,60 E(FA)-27	D(CN)-49 D(PA)-62 D(F2)-53 D(F4)-51,60

Performance code (Same as Exhibit VIII-1)(Continued):
- F1 - Partial failure, no repair/modification planned
- F2 - Partial failure, repair/modification planned or under way
- F3 - Partial failure, repair/modification completed but not tested under design flow conditions
- F4 - Project performing as-designed with repair/modification in place
- FA - Complete failure; project abandoned or another method has been used to stabilize bank

STREAMBANK SURFACE PROTECTION

Upper and Middle Bank

The exposure to flow attack or inundation on the upper and middle elevations of a streambank usually is infrequent or occasional. The more prevalent variations in protection schemes involved kind of material, thickness, and whether the elements are interconnected, plus a few special treatments.

General Findings: In many instances erosive mechanisms (piping) acting on the upper bank following high river stages caused minor loss of bank material above the adequately protected lower level (O-many).

Where the streambed consists of a well-consolidated clay or other geologic control, the stabilization measures should be designed to provide complete upper bank protection with only minimum toe protection (Y-38).

Where one streambed consisted of a well-consolidated clay, the stream overran the resistant clay bed during an extreme flow and scoured the upper banks to over twice their original width (Y-38).

Overbank Drainage Control

Cost: Varies widely with site conditions.

Findings: Overbank drainage from interior areas must not be permitted to flow over and down an unprotected slope. Outlets should be provided where required to conduct the water to the river (N-57).

Natural levees along top bank should be left undisturbed, as man-made replacements may not be adequate and may alter the overbank drainage patterns. Control of overbank drainage is necessary to prevent damage to the structure (Y-44, 47, 48).

Control of overbank drainage is essential to prevent washouts of natural or filter materials underlying protective works (O-9).

Monolithic (Low Porosity) Cover

General Findings: Monolithic-type bank stabilization structures may prevent the seepage of water through the bank, thereby creating excessive hydrostatic pressures in the banks. If pressure release is not provided, mass bank and structural failures may occur (Y-38, 43).

Monolithic Cover (Earth Type, Chemical Stabilizer)

Cost: Spray-on \$0.40/sq ft.

Findings: Spray-on stabilizers can be useful during construction and/or repair of streambanks to protect these denuded areas from erosion by rainfall and wind until vegetation can be reestablished (L-G).

Monolithic Cover (Earth Type, Others Being Evaluated)

Items: Soil-cement \$365-643/ft (M-30; N-68) and clay blanket.

Monolithic Cover (Anchored Membrane)

Cost: ($3.26/sq ft).

Findings: The membrane blanket can be used as a light protective surface to prevent erosion by current and wave action (L-DC, BB).

Membrane materials will protect streambanks and riverbanks from erosion during normal streamflows as long as banks remain stable. Banks at the test site and throughout the river basin failed during periods of rapid drawdown after an extended bank-overtopping flood. When the banks failed at the test site, material failures and displacement of anchor ditches occurred (L-BB).

Monolithic Cover (Filled Mats)

Cost: Fabriform $154-647/ft; MESL $3.61/sq ft.

Findings: The Fabriform suffered partial failure from undermining at one site (E-15).

The MESL method can be used as a medium-type protection when very loose surface conditions exist on banks. The stepped MESL, heavy-duty protection can be used in areas where banks have caved vertically or nearly vertically and without extensive grading and shaping of the banks (L-BB)

See also bank failure comment for anchored membrane item above.

Monolithic Cover (Others Being Evaluated)

Item: Ice (E-34).

Loose Material Cover (Porous, Rock Type)

Cost: $50/233/ft. Varies with availability of materials.

General findings: Stone riprap remains the most used material for protection against streambank erosion, although the methods of application and design vary widely and have provided protection ranging from poor to excellent, with the majority being excellent. Stone riprap is flexible and is neither impaired nor weakened by slight movement of the bank resulting from settlement or other minor adjustments. Local damage or loss is easily repaired by the placement of more rock. If riprap is exposed to fresh water, vegetation will often grow among the rocks, adding structural and aesthetic value to the bank (E: 32 of 50 projects).

Loose Material Cover
(Materials, Steel-Furnace Slag)

Cost: $80-115/ft.

Findings: Steel-furnace slag was effective and economical although some environmental concern exists due to leachates from the slag (O-1, 2, 3, 7).

Loose Material Cover
(Materials, Soil-Cement)

Cost: $500/ft.

Findings: Site-specific testing is needed to determine application rates and curing rate (E-3).

Loose Material Cover (Materials, Others Being Evaluated)

Items: Graded riprap, quarry-run rock ($50-233/ft), quarry waste, spalls, field stone, demolition rubble ($125-381/ft), chalk, and low-grade materials.

Loose Material Cover (Size of Material)

General findings: Size ranges from large (boulders) to small (gravel) and may be specially graded or used in the available mix.

Loose Material Cover (Placement)

General findings: Effectiveness of the stabilization measure can be nullified by construction delays, as changes in stream patterns and bed elevation can occur from the time of design survey to construction. All possible measures should be taken to expedite the time between design and construction (Y-47).

Onsite changes by construction personnel are sometimes necessary but should be closely coordinated with the designers. For example, rather than removing a protruding clay plug at one project and aligning the stone toe protection as designed, the stone was placed along the protruding bank line, thereby creating a point of discontinuity in the structure (Y-40).

Loose Material Cover (Placement, Windrow on Surface or Bench or in Trench)

Cost: $52-162/ft.

Findings: An estimate of the maximum bed scour along the toe of the structure is critical in determining the amount of material necessary. Windrow revetments can easily be constructed by land-based methods (resulting in reduced heavy equipment requirements) and during cold temperatures when the river is frozen. Smaller gradation (200-lb maximum weight) forms a more dense, closely chinked protective blanket layer than a large gradation (500-lb maximum weight). A stone windrow refusal extending landward into the bank is mandatory at the upstream end of each segment to preclude erosion flanking the structures. The buried trench windrow revetment is more desirable to environmentalists because it is not visually apparent. The windrow technique particularly lends itself to the protection of adjacent wooded areas, or placement along stretches of presently eroding, irregular bank line (M: 17 projects).

A rectangular cross section was the best configuration and is most easily placed in an excavated trench of the desired width. The second best shape was trapezoidal which provides a steady supply of stone for a uniform blanket on the eroding bank line. The size of stone used in the windrow was not significant as long as it was large enough to resist being transported by the stream. Larger stone sizes will require more tonnage than smaller stone sizes to produce the same relative thickness of final revetment. High banks tended to produce a nonuniform revetment alignment, due to a tendency for large segments to break loose and rotate slightly, whereas the low banks simply "melted" or sloughed into the stream (L-H).

Loose Material Cover (Placement, Others Being Evaluated)

Items: Surface layers of various designs with or without filter layers between the soil and the protective material.

Manufactured Elements (Precast Concrete Blocks, Gobi and Monoslab)

Cost: $57/ft.

Findings: The Monoslab was effective on a small creek (E-26).

Manufactured Elements (Paper or Fabric Bags Filled with Sand, Dry Sand-Cement, or Grout)

Cost: Sand, dry sand-cement mix $58-113/ft; grout $165/ft.

Findings: Nylon-reinforced bag protection placed on a relatively steep slope experienced a partial failure due to some of the bags sliding down the bank. The bags were also subject to ice damage (O-4, 9).

Manufactured Elements (Others Being Evaluated)

Item: Hay bales (N-54).

Porous Matting Cover (Metal or Fiber Mesh or Matting)

Cost: $25/ft.

Findings: Wire mesh matting is ineffective in providing interim erosion protection for establishment of vegetative growth (N-57).

Porous Matting Cover (Used Auto Tires)

Cost: $61-683/ft.

Findings: Used automobile tires, either as a wall or a mat, were effective, except for occasional vandalism problems and sliding of mats on steep, granular material slopes (O-1, 3, 6).

Used auto tires filled with gravel were successfully used by private landowners collecting free materials and doing the work themselves (E: 4 projects).

Stone fill should be used in rubber tire mattresses rather than random earth fill (N-54). If native soil rather than stone fill is used, a willow sprout or shrub should be planted in the center of each tire.

Porous Matting Cover (Others Being Evaluated)

Items: Gabion mattress, lumber mat, precast blocks attached to porous membrane, wire mesh over crushed stone ($115/ft).

Vegetation

General findings: Vegetation has been successfully used on upper banks in conjunction with structural protection on the lower bank (E-several).

All-vegetation schemes are not recommended (O-2).

Where existing vegetation was left undisturbed, the effectiveness of bank protection was increased (especially woody vegetation). Some soils are not conducive to vegetative growth (Y-40).

A grid/vegetation system is recommended where something more substantial than vegetation alone is required. Spray-on stabilizers are effective aids in the establishment of vegetation (L-G).

Effectiveness of vegetative treatments generally depended on whether or not they had time to take hold prior to the high-water season (Y-38).

The vegetation should be planted at the beginning of the growing season and repaired as necessary until established (N-57, 74).

If vegetation is used in conjunction with other methods, planting should not be attempted after late fall (O-general).

Vegetation (Grass)

Cost: \$4-12/ft.

Findings: A number of specific plants and grasses were found to provide effective vegetation cover (O-general).

Mulching with hay and plastic netting aided the establishment of grass (N-54, 55).

Vegetation (Woody Shrubs)

Cost: \$12-50/ft.

Findings: Woody vegetation seemed to provide a more effective bank protection than nonwoody vegetation (Y-38).

Vegetation (Controlled Growth)

Cost: \$0.19-0.51/ft.

Findings: Stream renovation or restoration by selective clearing and snagging can improve channel flow conditions and in many cases relieve the erosive action along the streambanks, especially for small streams. Hand-labor crews with occasional machinery assistance can accomplish much of this kind of work with few or no long-term impacts on the floodplain environment. One such system observed during the course of the Section 32 Program was developed by a private citizen in northwest Ohio and is being evaluated and documented by the Institute of Environmental Sciences, Miami University, Oxford, Ohio, under contract from the Corps of Engineers (Institute of Water Resources). That technique includes these six steps (not necessarily followed in this order):

(1) Remove log jams in a manner to make maximum use of the streamflow to move the material and to make use of the cut materials in arrangements to deflect the flow and/or protect the bank.
(2) Protect eroded banks by anchoring brush and logs at appropriate locations to slow the currents and to direct the flow away from the bank.
(3) Remove or relocate sand and gravel piles, felled trees, or logs by digging small pilot channels through the bar.
(4) Revegetate on bank and in new sediment deposits along bank. Control tree canopy over stream to help control bank-line vegetation.
(5) Remove potential obstructions by cutting or trimming dead or outwardly leaning trees along bank, leaving stumps and roots intact.
(6) Maintain the channel by periodic inspection of channel performance and doing additional or "repair" work promptly.

A very important aspect of this technique is careful, periodic observation and good understanding of the streamflow characteristics along the full length of the project.

Similar work was conducted by the Soil Conservation Service in 1979 on the Wolf River in Tennessee. Costs were about ten times those cited above.

Lower Bank and Toe

The exposure to flow attack or inundation of the lower bank and toe is usually continuous or very frequent. As for the upper and middle bank, the more prevalent variations in protection schemes involved kind of material, thickness (or mass), and whether the elements are interconnected, plus a few special treatments such as bulkheads.

General findings: Protections placed in the proximity of normal pool elevation were found to be adequate to stabilize the toe of the banks against current-related tractive forces (O-general).

Where bed degradation is very widespread, as in the hill streams of Mississippi, protection of the bank toe appears to be an important factor. Bank stabilization measures without toe protection were successful in some instances; however, if bed degradation is apparent or anticipated, or in bends having more than slight curvature, then toe protection is needed, or structures must be designed to accommodate expected channel deepening (Y-40, 41, 43).

Rock toe protection with low-cost upper bank protection generally functioned satisfactorily against the flow events experienced to date (N-53, 54, 61).

Monolithic (Low Porosity) Cover (Being Evaluated)

Items: Grout-filled mats (see comments above for upper and middle bank monolithic cover, filled mats).

Loose Material Cover (Porous, Rock Type)

General findings: See comments above for upper and middle bank loose material cover, porous, rock type.

Loose Material Cover (Materials Being Evaluated)

Items: Graded riprap, quarry-run rock, quarry waste, spalls, field stone, demolition rubble, and steel furnace slag. (See comments above for upper and middle bank loose material cover materials.

Loose Material Cover (Size of Material)

Findings: Size ranges from large (boulders) to small (gravel) and may be specially graded or used in the available mix.

Gravel cover over the stone toe of composite revetment is provided for aesthetics only and does not supply additional erosion control. However, the gravel allows easier access to the river for wildlife and enhances vegetation growth (M-several).

The use of reasonably well-graded material is adequate in windrows and is less expensive than a specified gradation (M-36).

Loose Material Cover (Placement)

Findings: See comments above for upper and middle bank loose material cover placement.

Scour pockets were observed at the downstream edge of some structures as a result of the eddy action of the water flowing over the downstream stone tiebacks and at the point of transition from complete upper bank paving to longitudinal stone toe protection (Y-42,43).

Adequate filters, either granular or fabric, are needed between the protective covering and noncohesive bank material. When filter fabric is being used in lieu of granular filters in such locations, care must be taken to ensure that the fabric is not punctured and that the sides and toe of the filter fabric are trenched, or otherwise sealed to the bank, so that leaching of the bank material does not occur (L-H).

Model test results confirm experience that riprap stability increases with increasing thickness of riprap (L-H).

In some projects no difference in performance was noted between protective covers placed with or without filters (Y-several; N-54, 55).

Loose Material Cover (Placement, Windrow on Surface or Bench or in Trench)

Findings: See comments above for upper and middle bank loose material cover placement, windrow.

Windrow revetment structures do not alter the general flow regime of the river. The material application rate should be determined by the channel depth, bank height, and material size and by estimating the expected maximum bed scour along the future structure alignment. When minimum material rates are used, monitoring is necessary to determine if the stone supply in the initial windrow is adequate and if a second construction treatment is required. After adequate coverage of the protected slope has been provided, excess stone may be salvaged from the windrow and used elsewhere (M-36).

Loose Material Cover (Placement, Composite Revetment)

Cost: \$41-153/ft.

Findings: Lower (below water surface) toe zones can effectively function with low-grade material (i.e., soil-cement, low-grade chalk, etc.) because this zone is not affected by frequent freeze-thaw and wet-dry cycles (M-12, 31).

Model studies indicated that the toe-fill was the most influential component of the reinforced revetment in controlling bank erosion (L-H).

In a model demonstration of toe protection without tiebacks, the higher stages eventually flanked the toe protection (L-H).

Manufactured Elements (Precast Concrete Blocks and Filled Bags)

Cost: 3.3-ft-diam Longard tube \$205/ft.

Findings: See comments above for upper and middle bank manufactured elements.

Longard tubes experienced vandalism and had to be repaired (O-5; N-56).

Porous Matting Cover (Riprap-Filled Cells or Grates)

Findings: Much smaller riprap can be used to stabilize bank slopes with the riprap-filled grates. A model demonstrated that the grates must be anchored if constructed of a lightweight material and the riprap-filled cells failed mainly due to attack at the toe and subsequent underminings of the grates. This concept has been used in Russia on navigable waterways to protect against erosion from wave attack (L-H).

Porous Matting Cover (Used Auto Tires)

Cost: \$61-683/ft.

Findings: See comments above for upper and middle bank matting cover, used auto tires.

Porous Matting Cover (Others Being Evaluated)

Items: Gabion mattress, lumber mat, precast blocks attached to porous membrane, wire mesh over crushed stone.

Bulkheads (Gabions Filled with Rock, Cobbles, Rubble, etc.)

Cost: \$33-126/ft.

Findings: Gabions were effective in establishing a low-flow channel with vegetated upper banks (E-20).

Bulkheads (Used Auto Tires)

Cost: On posts \$15/ft; chained and filled with sand or gravel \$150-200/ft.

Findings: Tire wall protections were subject to vandalism in some instances (O-1).

See comments above for upper and middle bank porous matting cover, used auto tires.

Bulkheads (Others Being Evaluated)

Items: Cribs (concrete, 12-ft high \$625/ft; or timber \$223/ft; both with filler), wood sheet piling.

Vegetation

General Findings: See comments above for upper and middle bank vegetation, controlled growth.

BANK MASS STABILITY (OTHER THAN PROTECTION AGAINST TOE EROSION)

Grading to Stable Slope

Cost: Varies widely with site conditions.

Findings: Design project to maintain slope stability for the normal condition, the eroded channel bed condition, and drawdown conditions (N-68).

Bank-instability-causing mechanisms acting mainly in the upper bank horizons are primarily drawdown-related and also depend on the composition of the bank material (O-general).

Subsurface Drainage

Cost: Varies widely with site conditions. Usually included as a part of the primary protection.

Findings: Placement of filter cloth, or bedding material, etc., was substantially helpful (O-general).

Piping of soil on drawdown or from normal perched water flows requires a filter material to prevent the washing of the natural soil through the blanket protection provided (N-57).

Minor loss of bank material due to piping was observed in the upper bank at several sites after flood periods (O-general).

Others Being Evaluated

Items: Rock-fill stability berm, bulkhead (retaining wall).

OVERALL CHANNEL STABILIZATION OR MODIFICATION (CONTROL OF FLOW ATTACK AGAINST BANK)

Grade Control of Channel Bottom

Findings: Channel bed degradation was a significant failure mechanism. Rock and sheet-pile structures were effective for low structures and reinforced concrete was used on the larger structures. Gabions were used at one project (E-several).

Grade-control structures have proved quite effective in halting streambed degradation. In some instances degradation has been halted by a riprap key downstream of the preformed scour pocket, box culverts, or concrete rubble in the streambed; however, these techniques are only temporary measures and should not be considered as methods of halting bed degradation permanently (Y-45, 48).

A head-cut had already progressed upstream of the site of a proposed grade-control structure, thereby severely limiting the effectiveness of the structure. All possible measures should be taken to expedite the time between design and construction (Y-46).

Items being evaluated include: concrete drop structures, sheet-pile weir with rock sill.

Hold or Modify Flow Alignment

General Findings: During periods of high and low flows, the location of the major point of attack will vary. It is necessary to define the limits for this point of attack to provide adequate bank protection for both high and low flows. Alignment of the structures should provide a smooth transition from bendway to bendway for both the high-water and low-water paths (Y-40, 41).

Longitudinal Controls (Parallel to Eroding Bank)

These include longitudinal dikes or retards (with various heights, distances from bank, and connections to bank).

Findings: In areas subject to river freezing, protective works constructed parallel to the direction of the current are subject to less ice damage than those constructed perpendicular to the flow (N-53).

Longitudinal Rock Fill

Cost: Reinforced revetment $57-182/ft; longitudinal stone dike $14-142/ft.

Findings: Low-grade material can be effectively utilized in the lower toe zones of the structure which are not affected by frequent freeze-thaw and wet-dry cycles. Prolonged periods of high flows may result in some upper bank erosion until a high-level bench is established. Since the structure is relatively low and the tiebacks are buried and covered, the structure is less conspicuous and more aesthetically attractive (M-12, 31).

These structures were found to be a very effective means of controlling streambank erosion. The purpose of the tieback is to prevent high flows from concentrating landward of the toe-fill (L-H).

Longitudinal stone dikes which provided effective toe protection were the most successful bank stabilization measures studied (Y-38 to 43).

Longitudinal Fabric Tube (Sand, Gravel, or Concrete Filler)

Cost: 3.3-ft-diam Longard tube \$205/ft.

Findings: The Longard tube protection was vandalized and had to be repaired (O-5).

Longitudinal Fence (Timber or Wire; with or Without Rock at Base)

Cost: Timber \$22-34/ft.

Findings: On navigable streams, light protective structures placed in the water, such as fences, etc., are subject to damage from tow traffic (O-5).

Floating ice and debris uplifted and pushed down timber and wire fence dikes (N-60).

In the model, toe scour of longitudinal fence retards was shown to be an important consideration (L-H).

Longitudinal Open Frames (Jacks)

Cost: \$18-85/ft.

Findings: Not effective in high-velocity flows. Floating ice and debris uplifted and pushed down Kellner Jack Fields (N-60).

Jacks were successfully used on three existing projects. Proper installation (alignment, anchoring, and spacing) is required and some maintenance is common (E-34, 46, 50).

Longitudinal Anchored Trees

Cost: \$24/ft.

Findings: Tree retards have a short functional life span and if near bank-line shoals do not develop shortly after placement, the retards may not be effective. Flow fluctuations, ice, and beavers destroy the tree elements. Higher flows overtop the trees and may continue to erode the unprotected banks. The trees and the created bars provide excellent fish habitat (M-29).

See comments above for upper and middle bank vegetation, controlled growth.

Longitudinal Bulkheads

General Findings: See comments above for lower bank and toe bulkheads.

Longitudinal Controls (Others Being Evaluated)

Items: Fence cribs filled with hay \$33/ft; tires \$29-33/ft.

Protruding Controls (Transverse or Angled Dikes of Various Heights, Lengths, Alignment, Spacing, Materials, and Connections to Bank).

Findings: Minor ice damage was observed on transverse dikes after spring breakup of frozen river (N-53).

Protruding Hard Points (Rock, Concrete Pile)

Cost: Rock $9-85 ft.

Findings: Hard points are effective along relatively long, slightly convex-shaped, or straight bank lines. Placement of hard points along an acute channel curve will necessitate excessive quantities of stone or structures spaced very close together (L-H).

The stone spur and stone root portion of each hard point are both mandatory for structure effectiveness. The quantity of stone in the spur must be adequate to hold the flow away from the bank, as the quantity of stone in the root would not likely be adequate to protect the bank from erosion (L-H).

The lower toe zone below normal water surface of the spur can be constructed using large stone or low-grade material and the remaining portions of the hard point should be constructed using better quality, medium-sized stone (M-several).

Hard points have experienced some degradation along the upstream side of the spur and root which results from high flow periods and spring ice breakup (M-12).

Embedded concrete-pile hard points were found to be very costly from casing the drilled holes to preclude slumping before placement of the concrete. Also, moving the heavy construction equipment was very destructive of the vegetation on top of the bank (N-66).

Stone used in the outer edge of a few dike hard points was dislodged by the ice jam and flows (N-53).

Areas left unprotected between hard points are subject to erosion in a scalloping effect which can be held to acceptable limits by proper spacing of the hard points (N-51, 62).

Hard points have only limited environmental impact on upper bank vegetation, because only minor timber clearing is required for construction access and stone root placement (M-several).

Protruding Spur Dikes (Board, Cable, or Wire Fence; with or Without an Apron or Mattress Along the Base)

Cost: Board $34-115/ft; cable $58/ft.

Findings: Permeable spur dikes constructed of board fence anchored to steel piling have been unsuccessful at two existing projects (E-5, 31).

Spur dike roots should be protected from scour caused by vortices set up along the upstream and downstream faces. Aprons are effective in limiting the depth of scour at the spur dike's toe (L-H).

Protruding Earth-Core Dikes

Cost: $35-72/ft.

Findings: The earth-core dike structure is an appropriate erosion control structure for only the larger rivers. A notch for some flow through the dike is essential in the design of an earth-core dike if a slack backwater area downstream of the structure is a planned environmental objective (M-24, 30).

Protruding Open Frames (Jacks)

Cost: $18-85/ft.

Findings: See comments above for longitudinal open frames.

Protruding Controls (Others Being Investigated)

Items: Fabric bags or tubing with filler ($56 ft), gabions, pile dikes (with apron or fill), vane dikes, and transverse stone dikes ($23-130 ft).

Wave Reduction

Cost: Breakwater fence $150 ft; floating tire breakwater $300 ft.

Findings: Structures placed in the river, such as wave fences and floating tire breakwaters were damaged from impacts by tows and also experienced problems with debris accumulation (O-5, N-59).

GENERAL OBSERVATIONS

Throughout the program some streams responded more effectively to bank stabilization measures than others. This phenomenon can be attributed to the rapid rate of change of the morphologic parameters (width, depth, etc.) in the unstable streams. Streams that have been significantly altered due to bed degradation undergo a rapid rate of change in width, depth, and other channel parameters. After a certain period of time, this rate of change decreases as the stream begins to adjust to a new state of relative equilibrium. As this adjustment approaches the new equilibrium state, bank stabilization measures have the greatest chance of success. Construction to stabilize the stream during the rapid transition state will require more massive and costly protective works to compensate for the increased threat.

Before any stabilization measures are planned, as much data as are available should be analyzed. This may be accomplished through a research of old plan maps, surveys, topographic maps, aerial photographs, field investigations, historical documentation of the area, and discussions with local residents and agencies familiar with the particular stream. This will assist designers to understand how the system has responded to changes in the past and how it may respond in the future.

Vandalism in urban areas is a problem that should be considered in the design and selection of protective systems. This could be a problem for technically effective methods. Efforts to dismantle the protection, fires, cutting knives, hatchets, etc., should be anticipated (O-general; N-56).

PART XV: PROCEDURES AND CONSIDERATIONS FOR PREVENTION OR CORRECTION OF STREAMBANK EROSION

INTRODUCTION

A systematic approach is needed in analyzing the needs and problems encountered in a streambank erosion problem, establishing the desired objectives and applicable courses of action, developing and evaluating alternative solutions, and proceeding with the selected plan. This part of the Final Report is a brief summary of the various procedures and considerations that are involved in taking action to prevent or correct streambank erosion problems and are generally applicable by any governmental body, organization, or individual involved with such a problem. The complex planning and evaluation procedures described in the following summary are required for large projects involving long reaches of streams or for projects having significant impacts on public interests. Most streambank protection projects by individual landowners can be dealt with much more simply, but even a cursory review of these procedures should be beneficial in planning the smallest projects.

Technical guidance resulting from the Section 32 Program is being incorporated into pertinent Corps of Engineers technical guidelines. An information pamphlet is being prepared to assist landowners and local governments in developing plans of action to prevent or minimize damage resulting from streambank erosion or failure. (See last section of this Part.) Erosion and bank instability problems are complicated and determination of the specific causative mechanisms is often difficult. More than a visual observation or a one-shot assessment is usually required. Erosion problems (material removed by surface scour) and the bank instability problems (from toe scour, sudden drawdown, or seepage) are frequently difficult to separate into neat packages. Solutions of these problems, therefore, require the close cooperation of the two disciplines normally concerned with water and soil—namely, hydraulic and geotechnical engineering. For most problems, theoretical tools and techniques are available for an analysis; however, the initial diagnosis requires considerable judgment and insight to avoid a waste of efforts and funds. In nearly all cases a substantially better solution can be obtained with professional assistance (engineering, construction, legal, and environmental) because of the many interacting complexities of the problem.

Section 10 of the River and Harbor Act of 1899 prohibits the unauthorized obstruction or alteration of any navigable water of the United States, including any activities that would alter or modify the course, condition, location, or physical capacity of the navigable water. Section 404 of the Clean Water Act of 1977 prohibits any unauthorized discharge of dredged or fill material into the waters of the United States. Other Federal, State, and local laws concern the protection of life, property, the environment, and various other activities and factors of the public interest. Consequently, there must be proper planning and evaluation of the proposed activity (such as streambank protection) with regard to the probable impact on the public interest, whether the activity is conducted by Federal, State, or local governments, by organizations, or by individuals. Also, the responsible Corps of Engineers District office should be contacted early with regard to permit requirements.

In addition to the project design and evaluation of various construction alternatives relative to physical performance, evaluation of the probable impact (including cumulative impacts) which the proposed activity may have on the public interest requires a careful weighing of relevant factors. The benefits that may reasonably accrue from the project must be balanced against its reasonably foreseeable detriments. The decision whether to proceed with a project, and if so, the conditions under which construction can proceed, are therefore determined by the

outcome of a general balancing process. That decision should reflect the national concern for both the protection and the utilization of important resources. All factors that may be relevant to the proposal must be considered. Among those are: resource conservation, economics, aesthetics, wetlands, cultural values, fish and wildlife values, flood hazards, floodplain values, land use, navigation, bank and bed erosion and accretion, recreation, water supply and conservation, water quality, energy needs, safety, food production, and, in general, the needs and welfare of the people.

PRELIMINARY INVESTIGATION

Initially, an expeditious analysis of a specific streambank problem should be made to define the scope and character of the damage, to decide whether protection work is at all feasible, and to determine what additional studies and planning are needed. Various aspects of the problem pertinent to the recent years past, to the present, and to the next few years should be considered. Needed information on physical characteristics of the problem includes: losses of adjacent land and improvements due to erosion or other damage to the streambank; any inadequacy of channel flow capacity resulting from debris, shoaling, increased discharge, encroachments, etc.; and any reductions in environmental quality with regard to the water, vegetation, wildlife, etc.

A field reconnaissance, a search through available records, and evaluation of the more likely potential causes of the bank erosion, bed degradation, and/or bank instability are principal features of the preliminary investigation. Basically, one must attain an understanding of the past and present behavior of the stream. The field reconnaissance should include recording and photographing the pertinent dimensions and features of the bank slope and surrounding area. Hydraulic and vegetative conditions at, upstream of, and downstream of the site and on the opposite bank need to be inspected and recorded. A search for floodmarks such as debris on the riverbank, trees, fences, etc., should be made if the problem is attributed to a particular flood or storm event. Any cultural features that would affect the channel system should be noted. Surface and subsurface soils should be sampled and classified at intervals both along the face and up the face of the exposed bank. A review of published geologic data on the depositional nature of the soil sediments in the area should be made. Rainfall and streamflow data should be tabulated. The personal knowledge and experience of local residents and personnel of local Corps, SCS, and other agency offices (geological, hydrological, and agricultural) can be sources of useful information. Finally, these data should be used to develop a list of potential causes for the eroding or unstable banks and/or bed degradation. This list should be used as the basis for subsequent detailed investigations.

Estimated direct and indirect costs should be determined for complete and partial losses of production, taxes, land improvements, channel improvements, aesthetic values, etc., as a result of the streambank erosion problem. A preliminary estimate should be made of the extent and cost of needed additional studies and protection work. Available resources should be identified for professional assistance in project design and supervision; for self-help labor, equipment, and materials; and for financial assistance from individuals, organizations, and various levels of government. (The current catalog of Federal Domestic Assistance from the Office of Management and Budget may indicate some possible sources of assistance.) If protection work appears feasible, additional investigations, appropriate to the nature and scope of the project, will be required for the project design relative to physical performance and impact on the public interest.

INVESTIGATION OF CHANNEL SYSTEM

The site-specific nature of each problem area makes it impossible to delineate all the items that could be investigated at a site, and the investigation of all such items probably is not necessary. Manpower, time, and funding limitations often restrict the amount of effort that can normally be applied to channel system problems. Therefore, a step-by-step investigation is recommended. The information and results from each step in the investigations should be carefully reviewed and detailed investigations planned accordingly to substantiate the potential causes of the problem, which were formulated in the preliminary stage. The following are some of the typical features of such an investigation to be accomplished in appropriate detail.

Channel Alignment and Shape

Sufficient topographic and hydrographic survey data are needed to establish the channel and valley alignments, cross sections and profiles, through and upstream and downstream of the problem area. Aerial photographs (vertical stereo and low-level oblique) should be examined for general channel alignment and historical information on meandering. Channel profiles should be investigated for "steps" that might show head-cutting and "flats" that might indicate sediment overload; and the apparent bed roughness should be described. Valley cross sections will indicate whether the channel is incised or perched and the significance of any natural levees. Reference marks for monitoring the active bank caving should be established. Vegetative cover types and sizes should be identified and documented.

Subsurface Explorations

An exploration program, tailored to the anticipated soil strata, is needed to develop the geologic profile and groundwater levels in the problem area. Piezometers are an absolute necessity for an understanding of groundwater and its changes due to river fluctuations and rainfall at the site. Banks that are suspected of failure resulting from poor subsoils or other internal reasons should be monitored with slope indicators set sufficiently deep. Soil samples obtained from the exploration program should be classified and tested. Special care should be taken during the drilling and soil classification work to locate thin layers and strata of either erodible or resistant subsoils along the banks and channel bottom. Any evidence of middle and upper bank seepage/piping should be documented. In situ permeability tests might be helpful to evaluate permeability and drainage characteristics of the bank. Triaxial and direct shear tests of weaker subsoils should be performed as found necessary.

Hydraulic Conditions

Information is needed on streamflow stages, discharges, velocities, and sediment conditions in the problem area, including flow durations, frequencies of peak discharges, and any apparent trends due to the climatic cycle, changes in land use, or flow control by dams, levees, or channel modifications. Where appropriate, velocity profiles and stage measurements should be obtained at the eroded area. If wave conditions are a factor influencing bank erosion or stability, wave gages should be installed and data accumulated. Where ice scour is a potential problem, measurements of thickness and direction of movement are needed.

Channel System Analyses

All of the above investigative procedures may not be necessary and budgetary restrictions may not permit them. Therefore, a well-planned, step-by-step investigative procedure followed with an evaluation of the data at the end of each stage is necessary to properly and efficiently diagnose the cause or causes of eroding or unstable banks. This requires close coordination in gathering data and studying the problem so that no element is overlooked. Too often the erosion is attributed to an incorrect or incomplete cause, and solutions are developed that are ineffective

and/or may result in further damages. The design of streambank protection structures or other structures that control or influence fluvial behavior should account for the natural physical environment of the site or reach in question, including the conditions upstream or downstream of the subject site or reach where the problems may originate or where events may influence the problems. This consideration often need not be greatly detailed, but some attempt should be made to trace the origin of actual or potential problems to possible or probable sources. The analysis of existing improvements on the same channel and neighboring streams may preclude a number of erroneous conclusions regarding the problem source. Also, the observation and analysis of naturally stable bends in the reach may reveal conditions (geologic or hydraulic) that can give direction toward more effective stabilization efforts at the problem site.

A determination of the probable sources or causes of the problems cannot be made without due consideration of the historic development of the problem. The use of historic documents, such as maps and aerial photographs, and the analysis of data extracted from these documents can indicate important trends that bear on the design of erosion control systems and should be an integral part of design investigations. The possible effects of cultural activities should be considered in the analysis of bank erosion causes. Land-use practices upstream from the problem areas may contribute to high sediment yields that, in turn, may result in channel widening and bank erosion in the lower reaches. In other regions, cultural activities may result in different responses, which also may result in bank erosion.

The geologic and geomorphic investigation of the causes of streambank erosion at a particular site or reach should include investigating the erosion characteristics, determining the mechanisms that are producing the erosion (such as channel deepening, channel widening, and/or sinuosity changes), identifying those hydraulic-geomorphic relationships that best describe the erosion mechanism, and evaluating those factors or activities that may be affecting the controlling hydraulic-geomorphic relationships (including analysis of both onsite and offsite factors). The channel should be classified generally as alluvial or nonalluvial, the former flowing over a deep bed of the same material it is transporting and depositing, and the latter over a thin layer of transported sediment with more resistant material underneath. The slope of the channel bank indicates the type of material (cohesive or noncohesive), stability, and/or trend of degradation. Channel widening or deepening is an indication of some types of instability. Existing vegetation can contribute to or protect against erosion, affect the soil stability and the hydraulic resistance, and be of ecological significance.

A geotechnical analysis to determine the critical slope for the existing or proposed bank, with the anticipated seepage patterns, should be accomplished. Conventional limit equilibrium stability analyses with either planar or rotational modes of failure are recommended. Conservative seepage and hydrostatic pressures, preferably based on piezometer and/or in situ permeability data, should be included in the analysis. Soils should be carefully sampled and tested and shear strengths evaluated, taking into account possible effects of past subsurface movements where applicable. An evaluation of the effects of the period of inundation and the drawdown rate of the river on the existing and/or proposed bank slope should be included. Improvements in the slope drainage resulting from toe or slope protections, internal drains, and other methods included in new construction should be considered. Bank slopes and protection works must be designed with an appropriate margin of safety reflecting variables, uncertainties, and quality of the investigations to provide acceptable reliability and risk.

Hydraulic analyses should include evaluations of existing sediment transport characteristics and the flow conditions that the soil can resist for comparison with measured or computed values expected in the critical flow event. Toe scour velocities and turbulent fluctuations are important factors to be considered and should be measured or estimated. Ice and wave conditions need to be evaluated as appropriate. Overland flow and local surface drainage effects should be included in these studies. In the absence of data for the specific problem site,

hydrologic and hydraulic conditions can possibly be determined by comparison with similar reaches on the same channel or on neighboring streams.

ENVIRONMENTAL CONSIDERATIONS

Streambank protection projects should be planned, designed, and constructed with consideration being given to environmental quality needs and project objectives. Environmental quality needs should consider maintenance or improvement of environmental resources within the project boundaries and avoidance of adverse impacts associated with the project. Some needs are project specific and are necessarily defined during the planning phase while others are mandated by existing regulations. Streambank protection projects that provide the required degree of protection should strive to meet environmental quality needs to the extent possible.

Environmental Impacts

Impacts of streambank protection projects are dependent on project location and regional characteristics. For example, in arid regions of the western United States, forested habitat may be restricted to riparian areas and be directly and extensively impacted upon by project construction; whereas in the southeastern United States, forested habitat may be more extensive, but changes in stream hydrology caused by the project can result in adverse impacts throughout the floodplain ecosystem. While general categories of impacts may be stated, site-specific and regional considerations and individual project features are critical in determining the magnitude and type of environmental impact. In some cases streambank protection is performed in conjunction with other projects having different purposes, and it is difficult to isolate impacts due to streambank protection alone. Categories of environmental impacts associated with streambank protection projects include aesthetic, physical, water quality, and biological.

- Aesthetic impacts most often occur because the natural appearance of the project area is disturbed or changed and replaced by an artificial appearance due to structures or channel alignment.

- The physical impacts of streambank protection can affect channel morphology, sediment-carrying capacity of the stream resulting in localized accretion or degradation, and stream hydrology. These physical effects tend to manifest themselves as changes in landscape diversity and associated wildlife habitat diversity or quality; for example, loss of side channels or shallow areas or replacement of natural bank with revetment. Losses or changes in habitat will affect wildlife either by a reduction or change in community structure; however, changes in habitat composition for a specific project can be either detrimental or beneficial depending on circumstances.

- Water quality impacts from changes in turbidity together with alteration of riparian habitat (e.g., shading) affect stream temperature and photosynthetic activities that in turn may affect algal or aquatic plant populations, dissolved oxygen, and other water quality parameters. Temporary changes in water quality may occur as a result of construction activities.

- Biological impacts can be broadly categorized into either terrestrial or aquatic. The major terrestrial impact involves alteration or elimination of riparian zone vegetation due to construction or project features. The riparian zone provides and supports a wide variety of plant and animal life and often provides critical habitat for certain species. Riparian vegetation also supports aquatic species by providing habitat for these species and input to the food chain. Channel stabilization can affect succession of riparian vegetation and

decrease diversity. Aquatic organisms, including benthos and fish, may also be affected due to changes or reductions in required habitats as a result of project features.

- Other impacts that may occur due to streambank protection projects include loss of wetlands and historic sites, changes in land use, increased recreational pressure, and economic or social impacts.

Measures to Meet Environmental Quality Needs

During initial project planning a wide range of alternatives is generally available. Many adverse environmental impacts can be avoided by judiciously considering these alternatives in the light of carefully defined environmental quality needs. The flexibility to consider project features, interrelationships to other projects, location, design alternatives, channel layout and geometry, degree of recreational access, and anticipated land-use changes provide many avenues to achieve this goal. In the later stages of project design, alternatives are restricted and changes to meet environmental quality needs may be difficult or costly to incorporate into the project. In all stages of the project, careful attention should be paid to avoid conflict in achieving environmental quality needs versus sound engineering practice. Additionally, the cost of implementing environmental quality needs and their benefits should be carefully considered.

Concepts that can be employed in design are the use of natural materials for bank protection, including consideration of vegetation alone (if adequate) or in combination with structural measures, maintenance of habitat diversity, minimizing impacts on the riparian zone, and allowance for some degree of channel migration to provide required habitat for aquatic and terrestrial species. Alignment or spacing of project features can contribute significantly to the aesthetic value of the completed project. Maintenance of habitats and their diversity is very critical to minimizing biological impacts and conserving the environmental resources of a project area. Provision of a riparian buffer zone with adequate access for recreation and wildlife should be coordinated with present and anticipated land use. Construction should be restricted to minimize impacts on the riparian zone, and steps should be taken to restore affected areas as soon as possible.

Streambank protection can be achieved while minimizing adv rse environmental impacts or maintaining the environmental resources of the project area. An approach that carefully integrates environmental quality objectives with project needs during all stages of the project is necessary to attain this goal. Balancing environmental and engineering considerations while weighing the benefits and costs of various alternatives provides a method to meet environmental objectives simultaneously with project needs.

SELECTION AND DESIGN OF STABILIZATION WORKS

On the basis of the preliminary investigation of the streambank erosion problem and the analysis of the channel system to determine the probable cause(s) of the problem, some objectives and courses of action should be apparent. These should include appropriate consideration of the numerous factors noted among the basic requirements at the beginning of this part of the report and should be set forth and described as specifically as possible. Plans for possible alternative protection methods can now be formulated, assessed, and evaluated.

Probable Cause(s) of Problem

The many possible causes of streambank erosion and failure are described in PART VII of this report. The cause(s) in any specific problem will probably be within these general phenomena:

- Generally high flow velocities removing bank material through considerable ranges of depth and distance along the bank.
- Local concentrations of high velocities resulting from the local channel boundary shape and removing material in somewhat limited areas.
- Undercutting of the bank due to bed degradation, local channel velocity patterns, and or low-lying strata of erodible bank materials.
- Bank materials of varying stability with respect to seasonal vegetative cover or exposure of highly erodible materials as bank sloughing or caving progresses.
- Structurally unstable banks subject to massive failures due to increase in shear stress and or decrease in shear strength.
- Wave attack from wind or passing vessels, or impact attack from ice or debris.
- Fluctuating water levels due to hydropower or flood-control operations.
- Weathering or chemical reaction.
- Water entering the channel over its banks and or rainfall on the banks.
- Increases in the stream's sediment-carrying capacity.

Remedial Measure Alternatives

The choice of viable alternatives from a seemingly endless variety of methods to protect a streambank against any of several causes of damage and failure is a formidable task. Therefore, as much knowledge, experience, and guidance as possible should be utilized from the efforts of others (past and present), the results of investigative work such as the Section 32 Program (see Exhibits VIII-1 and XIV-1), and design directives (as described in the last section of this Part and as available from other sources). The following categories of streambank protection techniques, from which more specific items can be derived, are not mutually exclusive and often could be used in combination:

- Direct bank protection with materials more resistant to erosion than the underlying soil due to greater density, mat-type construction, or reinforcement of the bank soils (as with vegetation).
- Dikes or devices to slow the flow velocities along the bank.
- Dikes or other techniques to shape the channel alignment locally or extensively so as to direct the flow away from the bank or reduce sharp curvature of the channel.
- Protection of the toe of the bank to prevent undercutting.
- Grade control of the channel bottom.
- Improving the structural stability of the soil mass of the streambank.
- Controlling flow of water entering channel over its bank.

Any substantial changes affecting the whole channel should be given very careful consideration so as not to initiate a "domino effect" of new problems resulting from an improper action to solve the original problem. If whole-channel improvements are necessary, the best scheme usually interferes the least with the natural stream condition. As much of the natural channel as possible should be used, and the water and sediment flow characteristics through the reach should be changed as little as possible.

Plans for Better Alternatives

A range of possible corrective and protective methods should emerge from the preceding consideration of causes and alternative remedial measures. A cursory review will probably

identify a number of obviously impractical schemes and some that seem obviously satisfactory. However, those in the middle range of being questionably satisfactory should also be given careful consideration. As the range of alternatives is narrowed, preparation of detailed plans, impacts, costs, resources, etc., can proceed.

- Design guidance from appropriate sources should be carefully reviewed for application to the specific problem and followed closely to avoid adverse results. Section 55 of Public Law 93-251 authorized the Secretary of the Army, acting through the Chief of Engineers, to provide technical and engineering assistance to non-Federal public interests in developing structural and nonstructural methods of preventing damages attributable to shore and streambank erosion.
- Local experience (both successful and unsuccessful) on the same stream or on neighboring, similar streams can be particularly helpful in selecting protection schemes and detailing plans.
- Locally available or otherwise lower cost alternative construction materials for the project should be sought and evaluated. Cost comparison should include transportation and handling.
- Constructibility of each project alternative is to be considered during its design. Constructibility is the ease with which a designed project can be built and the ease with which the plans and specifications can be understood. It encompasses compatibility of design, site, materials, methods, techniques, schedules, field conditions, and sufficiency of details and specifications and freedom from design errors, omissions, and ambiguities. Constructibility also depends upon recognition of unique problems and the appropriate application of design assumptions, principles, and specifications during construction.
- The anticipated performance of each alternative protection scheme over its expected life should be outlined. Consideration should be given to expected ranges and duration of flows, possible land-use changes, material strength and durability, anticipated maintenance, environmental conditions related to the project, etc.
- The alternatives of no protective work and a nonstructural plan should also be investigated. In problem areas where only very low-cost protection can be justified, a design for a lower degree of protection could be provided against a correspondingly lower degree of flooding than would usually be considered. This scheme would require close observation and prompt strengthening if, when, and where needed and overall improvement as resources became available.

Selection of Best Alternative

The choice of the best alternative method for streambank protection generally will be based on evaluation of the costs and benefits of the project. The approach to the choice usually will differ as to whether the costs and benefits accrue to a private individual or organization or to whomever they may accrue in a public project. In both instances there may be substantial regulatory constraints that must be observed and may have a significant influence on the benefits and costs. Considerations of the project economics should include intangible as well as both primary and secondary tangible factors. Since some costs will generally be one-time (i.e. construction), and other costs (i.e. maintenance) and most of the benefits will extend over the life of the project, comparisons should be made on the basis of average annual costs and benefits. Appropriate life expectancies, maintenance efforts, property values, production estimates, interest rates, etc., need to be quantified. Finally, a decision must be made, and the reasoning and arguments should be well documented for future reference in the event of extending the protection or investigating unexpected behavior (good as well as poor).

Permits

The Corps permit program began in 1899; its purpose was principally to avoid obstructions in navigable waters. Now, in response to changing environmental, social, and economic conditions, the program concerns not only the integrity of navigation channels but also the quality of the waters of the United States.

A Corps permit is required to locate a structure, excavate, or discharge dredged or fill material in waters of the United States. However, not every activity requires a separate, individual permit application. Certain activities and work have been authorized by nationwide permits and general permits. Some of these may pertain to streambank protection.

Nationwide permits have been issued for certain types of activities in all waters in the United States. These permits and their conditions are published in Sections 322.4 and 323.4 of Title 33 of the Code of Federal Regulations. If an activity is covered by a nationwide permit and applicable conditions will be met, there is no need to apply for an individual permit. In effect, activities authorized by the nationwide permits in the regulation are permitted in advance. General permits are issued by the local Corps District Engineer. They are similar to the nationwide permits, but are limited to smaller specified regions and may require some notification or reporting procedures. The District Engineer is authorized to determine those categories of activities in specified geographical regions that will cause only a minimal adverse environmental impact and to allow them with general permits. These will reduce delays by eliminating the need to process many individual applications.

Permit application forms and instructions are available from the Corps District Engineer office having jurisdiction over the area where the work is to be done. The completed forms together with project drawings are returned to that Corps office for review and approval. Each application is evaluated to determine the probable impact the structure or activity will have on the public interest. If there are no objections to the structure or activity, a permit usually will be issued within 60 to 90 days after the completed application is received. Many applicants are able to resolve minor objections by modifying their proposed project during the review process; but many Federal, State, and local agencies, as well as community groups and individuals, may become involved. If there are major objections or if an Environmental Impact Statement is required, processing time could be a year or more.

There are times during the evaluation process when the Corps finds that a project and its intended use will have an adverse impact on the public interest. If the Corps is concerned about a project, the applicant can:

- Discuss with a Corps representative the reasons that the application is unacceptable.
- Reconsider the plan and examine alternatives.
- Modify the original project design to eliminate the objectionable features.

Any work that requires a Corps permit should not begin before receipt of official authorization. Case-by-case consideration is given to violations, and the violators may be subject to:

- Civil and/or criminal court action.
- Fines of $500 to $25,000 per day.
- Imprisonment for up to 1 year.
- Removal of structures and materials.

CONSTRUCTION OF STREAMBANK PROTECTION WORKS

Nearly all streambank protection schemes will require some kind of physical effort for accomplishment, which may range from sowing seed to full-fledged construction. The needed plans and specifications for the work will vary with circumstances from the minimum required for a small job permit (or possibly none) to detailed and seemingly voluminous contract documents for large projects conducted by Government agencies. Whether stated formally in a contract or carried as a mental note by an individual, the materials should be of the most suitable grade for the purpose intended and all work should be performed in a skillful and workmanlike manner. Both contracted and self-help work should incorporate appropriate inspection and tests to assure an effective project as well as good return for the price paid.

Local Cooperation

The documents in support of Congressionally authorized Federal projects contain the authority for requiring local cooperation. Most requirements for local cooperation specify that local interests shall provide without cost to the United States, all lands, easements, and rights-of-way required for the project. The pertinent authorization for each individual project should be examined. Specific details of required local cooperation for projects under continuing Federal authorities are contained in the reports and approvals authorizing the work. Formal binding assurances must be obtained prior to commencement of construction.

Use of Government Plant and Hired Labor

Federal project work is done with hired labor and Government plant only when it is of a type in which contractors are not interested; where advertisement of the work results in procurement of unacceptable bids, and suitable Government plant exists and can be utilized as the basis of the Government estimate; or when special equipment or qualifications for doing the work are not generally available to the contracting industry. Bank revetment work with special Government-owned plant is an example of the latter case.

PROJECT DOCUMENTATION

The documentation of project condition and performance is a continuous process from the past through the present into the future, or from preconstruction through design and construction and the operational life of the project. Available historical data are important as the basis of design conditions and of projected conditions without the streambank protection. Design and construction records (design memorandum, plans and specifications, construction reports) establish the degree of protection expected and contain information on the foundation and underlying elements of the works. Operational records (inspection reports, weather, stages, flows, channel changes, maintenance) are important factors in determining the performance relative to design requirements. Particular note should be made as to whether changing conditions affecting erosion sites and streambank protection performance are natural or man-caused. Changes in land use and cultural features should be recorded relative to benefits accruing to the project and possible higher levels of damage in the event of project failure. Investigations for other projects in the vicinity may yield information that also is pertinent to the performance record of the streambank protection project. The minimum formal documentation effort should be at least a detailed, chronological listing through the years of all data, surveys, observations, reports, correspondence, comments, etc., pertaining to the project with information on where each item is filed.

INSPECTION AND MAINTENANCE

For economical, efficient, and reliable performance of streambank protection, simple but adequate inspection and maintenance programs should be established. Guidance for the preparation of such programs is given in a number of Corps of Engineers documents and the Code of Federal Regulations, Title 33, Chapter 2, Part 208, Flood Control Regulations. Proper inspection and maintenance programs and well-documented project performance also can often prevent or greatly forestall claims against the project sponsor in problems concerning streambank erosion, as well as contribute substantially to a just resolution in any litigation.

Inspection

A good inspection program will aid in obtaining uniform, brief, thorough information on streambank protection conditions and performance. This information is needed for use in planning maintenance operations and in evaluating performance of the protection methods. The performance data are valuable for verifying the design studies and for application to future streambank control problems. Visual inspections should be made during and after high flows and at least annually to detect any breaks, cracked or broken paving, disarranged stone, exposed banks, erosion, or other damage on the upper bank. During the low-water season, the condition of the lower bank protection can be observed, including soundings over the underwater area of the banks. Also, any of the sponsor's personnel having occasion to be at or near bank protection works should inspect for damage.

Maintenance

All methods of streambank protection will generally require some type of maintenance. Therefore, perpetual rights-of-way and construction easements need to be obtained prior to initial construction to allow for access to the project area to periodically monitor the structural condition and allow work on necessary repairs or reconstruction.

Periodic Repairs. Most erosion control protection methods can be classified into three general types with their respective maintenance requirements.

Rigid structures (sack revetment, asphalt pavement, clay blanket, concrete pavement), which cannot adjust to local riverbed or bank-line movement, may rupture at the surface from removal of foundation support by subsidence, undermining, outward displacement by excess hydrostatic pressure, slide action, or erosion of supporting embankment at the ends. The support should be reestablished by backfilling, construction of suitable underpinning, foundation protection, and substantial ties of undercut end sections into the bank. Excessive hydrostatic pressure from high-water stages or natural seepage can be prevented by keeping all weep holes open or by drilling new holes if seepage is evident. Coarse brush roots tend to break up the protective surface when exposed to severe wind or wave action. Cracks in the surface cover should be suitably filled immediately to prevent loss of supporting embankment material.

Flexible structures (articulated blocks, wire mesh netting, mattresses) are less susceptible to damage by distortion and can continue to function after moderate displacment. Wire mesh netting structure types may require general restoration of their integrity by replacing weak or damaged areas or closing gaps. Mattress-type construction along the toe of the bank is capable of considerable adjustment as the riverbed material is removed by erosion. The mattress must be kept intact as long as it remains exposed.

Self-adjusting structures (rock slope protection) are very flexible and are not weakened by slight movements of the bank resulting from settlement or other minor adjustment.

However, sufficient material must be available to maintain an effective blanket layer as the material moves to stabilize the natural bank. Additional material should be added as deemed necessary to ensure the integrity of the structure.

Rehabilitation or Reconstruction. When damage to an existing structure becomes so extensive that minor repairs will not be sufficient to restore the structure to an effective condition, rehabilitation or reconstruction will be necessary. A chronic problem area requiring continual repairs or rehabilitation should be specifically analyzed to determine the cause. Particular river conditions may make it more economical to change structure types or alter the flow pattern upstream rather than continually accomplishing costly rehabilitation.

NEW DESIGN GUIDANCE

New technical knowledge resulting from the Section 32 Program is being incorporated in pertinent Corps of Engineers technical guidelines. An information pamphlet is being prepared to assist landowners and local governments in self-help protection work for streambank erosion control. Publication of these items is expected to be within a year after this Final Report. Additional performance observations are expected from the demonstration projects and the findings will be incorporated in this guidance.

Engineering Technical Guidance

A Corps of Engineers Engineer Technical Letter (ETL) entitled "Streambank Protection" is being prepared to provide information on what was learned from the Section 32 Program and to provide current guidance on design procedures and techniques to follow when preparing plans for streambank protection against erosion and bank failure. The ETL will cover legislation and permits, river mechanics and geomorphology, streambank erosion and streambank failure, nonstructural and structural methods for streambank protection against erosion and bank failure, and inspection and maintenance. The ETL will be revised and expanded into an Engineer Manual when sufficient performance data become available from the demonstration projects constructed under the Section 32 Program.

Pamphlet

A pamphlet on streambank protection is being prepared for landowners and local governments who must deal with such problems. While there is no substitute for professional engineering assistance in solving such problems, economic constraints often preclude the availability of professional assistance. Thus, in many cases, local interests must act alone to protect an eroding or failing streambank.

The major focus of the pamphlet is to assist the landowner or local government in developing and following through with a plan of action to protect a distressed bank. The plan of action in the pamphlet is structured in seven steps:

(1) Identify those causes that have placed the streambank in a distressed condition.

(2) Conduct the preliminary planning needed to determine if bank protection is feasible.

(3) Select an appropriate bank protection method.

(4) Develop a construction plan.

(5) Acquire any necessary permits.

(6) Construct the project.

(7) Conduct periodic inspections of the completed project and perform required maintenance.

By following this approach in a self-help effort, an effective and low-maintenance streambank protection project can be constructed with greater reliability than a project where the builder did not have the benefit of guidance provided in the pamphlet.

This pamphlet is also for those landowners and local governments who are fortunate enough to have their property or jurisdiction in a federally funded project area where streambanks are to be protected as part of the project. Local interests are often requested to participate in the planning and decision-making phase of such projects. The material in the pamphlet will provide beneficial background information that will enable individuals or local governments to more effectively communicate with project officials.

Corps of Engineers Offices

Information on permits and available design guidance on streambank erosion control can be obtained from the following Division and District offices of the Corps. Address inquiries to:

Commander, US Army Engineer Division, ____________

Lower Mississippi Valley	P. O. Box 80, Vicksburg, MS 39180
Missouri River	P. O. Box 103, Downtown Station, Omaha, NE 68101
New England	424 Trapelo Road, Waltham, MA 02254
North Atlantic	90 Church Street, New York, NY 10007
North Central	536 S. Clark Street, Chicago, IL 60605
North Pacific	P. O. Box 2870, Portland, OR 97208
Ohio River	P. O. Box 1159, Cincinnati, OH 45201
South Atlantic	510 Title Bldg., 30 Pryor Street, S. W., Atlanta, GA 30303
South Pacific	630 Sansome Street, Rm 1216, San Francisco, CA 94111
Southwestern	1114 Commerce St., Dallas, TX 75242

Commander, US Army Engineer District, ____________

Alaska	P. O. Box 7002, Anchorage, AK 99510
Albuquerque	P. O. Box 1580, Albuquerque, NM 87103
Baltimore	P. O. Box 1715, Baltimore, MD 21203
Buffalo	1776 Niagara St., Buffalo, NY 14207
Charleston	P. O. Box 919, Charleston, SC 29402
Chicago	219 S. Dearborn St., Chicago, IL 60604
Detroit	P. O. Box 1027, Detroit, MI 48231
Ft. Worth	P. O. Box 17300, Ft. Worth, TX 76102
Galveston	P. O. Box 1229, Galveston, TX 77553
Huntington	P. O. Box 2127, Huntington, WV 25721
Jacksonville	P. O. Box 4970, Jacksonville, FL 32232
Kansas City	700 Fed. Bldg., Kansas City, MO 64106
Little Rock	P. O. Box 867, Little Rock, AR 72203
Los Angeles	P. O. Box 2711, Los Angeles, CA 90053
Louisville	P. O. Box 59, Louisville, KY 40201
Memphis	668 Clifford Davis Fed. Bldg., Memphis, TN 38103
Mobile	P. O. Box 2288, Mobile, AL 36628
Nashville	P. O. Box 1070, Nashville, TN 37202
New Orleans	P. O. Box 60267, New Orleans, LA 70160
New York	26 Fed. Plaza, New York, NY 10278

Norfolk	803 Front St., Norfolk, VA 23510
Omaha	6014 USPO & Courthouse, Omaha, NE 68102
Philadelphia	US Custom House, 2nd & Chestnut St., Phila, PA 19106
Pittsburgh	Federal Bldg., 1000 Liberty Ave., Pittsburgh, PA 15222
Portland	P. O. Box 2946, Portland, OR 97208
Rock Island	Clock Tower Bldg., Rock Island, IL 61201
Sacramento	650 Capitol Mall, Sacramento, CA 95814
St. Louis	210 Tucker Blvd. N., St. Louis, MO 63101
St. Paul	1135 USPO & Custom House, St. Paul, MN 55101
San Francisco	211 Main St., San Francisco, CA 94105
Savannah	P. O. Box 889, Savannah, GA 31402
Seattle	P. O. Box C-3755, Seattle, WA 98134
Tulsa	P. O. Box 61, Tulsa, OK 74102
Vicksburg	P. O. Box 60, Vicksburg, MS 39180
Walla Walla	Bldg. 602, City-County Airport, Walla Walla, WA 99362
Wilmington	P. O. Box 1890, Wilmington, NC 28402

PART XVI: GLOSSARY

A listing of terms commonly used to describe streambank erosion and instability mechanisms, as well as terms related to streambank protection and river mechanics, is provided below:

Abrasion - Removal of streambank material due to entrained sediment, ice, or debris rubbing against the bank.

Angle of repose - The maximum angle (as measured from the horizontal) at which gravel or sand particles can stand.

Aggradation (bed) - A progressive buildup or raising of the channel bed due to sediment deposition. Aggradation is an indicator that a change in the stream's discharge and sediment load characteristics is taking place.

Alluvial fan - A cone-shaped deposit of sediment formed at the confluence of a stream and its tributary. If the sediment load of the tributary cannot be carried away by the stream, an alluvial fan forms.

Armoring - (a) Natural process whereby an erosion-resistant layer of relatively large particles is formed on a streambank due to the removal of finer particles by streamflow. (b) Placement of a covering on a streambank or filter to prevent erosion.

Articulated concrete mattress - Rigid concrete slabs usually hinged together with corrosion-resistant wire fasteners; primarily placed for lower bank protection.

Asphalt block - Precast or broken pieces of asphalt that can be hand-placed or dumped on a streambank or filter for protection against erosion.

Asphalt (bulk) - Mass uncompacted asphalt usually dumped from a truck (upper bank protection) or a barge (lower bank protection) that is placed to protect the bank against erosion.

Avulsion - A change in channel course that occurs when a stream suddenly breaks through its banks; usually associated with a catastrophic event.

Backfill - The material used to refill a ditch or other excavation, or the process of doing so.

Backwater area - The low-lying lands adjacent to a stream that may become flooded during periods of high water.

Bank - The side slopes of a channel between which the streamflow is normally confined.

Bed - The bottom of a channel.

Bed load - Sediment that moves by saltation (jumping), rolling, or sliding in the bed layer of a stream.

Bedrock - The solid rock underlying soils and overlying the mantle rock, ranging from surface exposure to depths of several hundred feet.

Bed slope - The inclination of the channel bottom.

Bituminous mattress - An impermeable rock-, mesh-, or metal-reinforced layer of asphalt or other bituminous material placed on a streambank to prevent erosion.

Blanket - Material covering all or a portion of a streambank to prevent erosion.

Braided stream - A relatively wide and shallow stream with multiple channels formed by islands and bars in the waterway.

Buffer zones - Areas of trees, grass, or other vegetation located between top bank and adjacent pastures or cultivated fields (also called greenbelts).

Bulkhead - A vertical or nearly vertical retaining wall or structure supporting a natural or artificial streambank.

Cation-exchange capacity (CEC) - The sum total of exchangeable cations that a soil can adsorb; expressed in milliequivalents per gram or 100 grams of soil.

Caving - The collapse of a bank by undercutting due to wearing away of the toe or an erodible soil layer above the toe.

Cellular-block mattress - Regularly cavitated interconnected concrete blocks placed directly on a streambank or filter to prevent erosion. The cavities can permit bank drainage and the growth of either volunteer or planted vegetation when filter fabric is not used between the mattress and bank.

Channel - A natural or man-made waterway that continuously or periodically passes flow.

Chemical stabilization - Streambank protection technique involving the application of chemical substances to increase particle cohesiveness and to shift the size distribution toward the coarser fraction. The net effect is to improve the erosion resistance of the material.

Clay - Material passing the No. 200 (0.074 mm) U. S. Standard Sieve that exhibits plasticity (putty-like properties) within a range of water contents and has considerable strength when air-dry (Unified Soil Classification System).

Clay blanket - Layer of compacted clay placed over cohesionless bank soils to protect them against erosive streamflow.

Concrete block - Precast concrete material placed on a streambank or filter to prevent erosion.

Confluence - The junction of two or more streams.

Constriction (flow) - A reduction in channel cross-sectional area that results in greater stream velocities and/or water depth.

Crib - A frame structure, filled with earth or stone ballast, designed to absorb energy and to deflect streamflow away from a bank.

Critical shear stress - The minimum amount of shear stress exerted by passing stream currents required to initiate soil particle motion.

Cross section - A diagram or drawing cut across a channel that illustrates the banks, bed, and water surface.

Crossing - The relatively short and shallow reach of a stream between bends; also called a crossover.

Current - Water flowing through a channel.

Cut bank - The concave wall of a meandering stream.

Cutoff - A new, relatively short channel (natural or artificial) formed when a stream cuts or is realigned through the neck of an oxbow or horseshoe bend. A cutoff can also develop as successive high-water flows develop a chute across the inside of a point bar.

Degradation (bed) - A progressive lowering of the channel bed due to scour. Degradation is an indicator that a change in the stream's discharge and sediment load characteristics is taking place.

Dike (groin, spur, jetty) - A structure extending from a bank into a channel that is designed to (a) reduce the stream velocity as the current passes through the dike, thus encouraging sediment deposition along the bank (permeable dike) or (b) deflect erosive currents away from the streambank (impermeable dike).

Discharge - Volume of water passing through a channel during a given time, usually measured in cubic feet per second.

Drainage basin - An area confined by drainage divides, often having only one outlet for discharge.

Eddy current - A vortex-type motion of a fluid flowing contrary to the main current, such as the circular water movement that occurs when the main flow becomes separated from the bank.

Energy grade slope - An inclined line representing the total energy of a stream flowing from a higher to a lower elevation. For open-channel flow the energy grade slope is located a distance of $U^2/2g$ above the water surface (U = velocity and g = acceleration due to gravity).

Ephemeral stream - A stream that flows only in direct response to precipitation and receives little or no water from springs or no sustained supply from snowmelt or other sources. An ephemeral stream's channel is at all times above the water table.

Erosion - Removal of soil particles from the land surface due to water or wind action.

Erosion control matting - Fibrous matting (e.g. jute, paper, etc.) placed or sprayed on a streambank for the purpose of preventing erosion or providing temporary stabilization until vegetation is established.

Fabriform - Grout-filled fabric mattress used for streambank protection.

Fascine - A bundle of brush, sticks, or timber used to make a foundation mat or to construct a revetment to protect a streambank against erosion.

Fence - A streambank protection technique consisting of wire mesh or timber attached to a series of posts, sometimes in double rows; the space between the rows may be filled with rock, brush, or other materials. Fences may be placed either parallel to the bank or extended into the stream; in either case these structures decrease the stream velocity and encourage sediment deposition as the flow passes through the fence.

Fetch - The area in which waves are generated by wind having a rather constant direction and speed; sometimes used synonymously with fetch length.

Fetch length - The horizontal distance (in the direction of the wind) over which wind generates waves and wind setup.

Filter - Layer of fabric, sand, gravel, or graded rock placed, or developed naturally where suitable in-place materials exist, between the bank revetment and soil for one or more of three purposes: to prevent the soil from moving through the revetment by piping, extrusion, or erosion; to prevent the revetment from sinking into the soil; and to permit natural seepage from the streambank, thus preventing buildup of excessive hydrostatic pressure.

Flanking - Erosion resulting from streamflow between the bank and the landward end of a river-training or a grade-control structure.

Flow slide - Saturation of a bank to the point where the soil material behaves more like a liquid than a solid; the soil/water mixture may then move downslope resulting in a bank failure.

Gabion - A wickerwork or wire mesh basket or cage filled with stone or other materials placed against a streambank to prevent erosion.

Gobi Block - Precast cellular concrete block often used as a substitute for riprap.

Geomorphology - That branch of both physiography and geology that deals with the form of the earth, the general configuration of its surface, and the changes that take place due to erosion of the primary elements and in the buildup of erosional debris.

Grade-control structure (sill, check dam) - Structure placed bank to bank across a stream channel (usually with its central axis perpendicular to flow) for the purpose of controlling bed slope and preventing scour or head-cutting.

Gravel - Rounded or semirounded particles of stone that can pass a 3-in. (76.2 mm) and be retained on a No. 4 (4.76 mm) U. S. Standard Sieve (Unified Soil Classification System).

Grout - A fluid mixture of cement and water or of cement, sand, and water used to fill joints and voids.

Hard point - A streambank protection technique whereby "soft" or erodible materials are removed from a bank and replaced by stone or compacted clay. Some hard points protrude a short distance into the channel to direct erosive currents away from the bank. Hard points also occur naturally along streambanks as passing currents remove erodible materials leaving nonerodible materials exposed.

Head-cutting - Channel bottom erosion moving upstream through a basin indicating that a readjustment of the basin's slope and its stream discharge and sediment load characteristics is taking place. Head-cutting is evidenced by the presence of waterfalls or rapidly moving water through an otherwise placid stream. Head-cutting often leaves streambanks in an unstable condition as it progresses through a reach.

Helical flow - Three-dimensional movement of water particles along a spiral path in the general direction of flow. These secondary-type currents are of most significance as flow passes through a bend; their net effect is to remove soil particles from the cut bank and deposit this material on the point bar.

Hydraulic radius - The cross-sectional area of a stream divided by its wetted perimeter.

Jack (jackstraw, Kellner jack) - A component of a river training structure consisting of wire or cable strung on three mutually perpendicular metal, wooden, or concrete struts.

Launching - Release of undercut material (stone riprap, rubble, slag, etc.) downslope; if sufficient material accumulates on the streambank face, the slope can become effectively armored.

Levee - An embankment generally landward of top bank that confines flow during high-water periods, thus preventing overflow into lowlands.

Longard tubing - Sand-filled tubes (synthetic material) placed either parallel or at an angle to the streamflow for streambank protection.

Lower bank - That portion of a streambank having an elevation less than the mean water level of the stream.

Mattress - A covering of concrete, wood, stone, or other material used to protect a streambank against erosion.

Meandering stream - A single channel waterway having a pattern of successive deviations in alignment and flow direction.

Middle bank - That portion of a streambank having an elevation approximately the same as that of the mean water level of the stream.

Natural levee - A low, alluvial ridge adjoining the channel of a stream formed by sediment deposited by floodwaters that have overflowed the channel banks.

Organic mixtures and mulches - Any of a number of agents (e.g. petrochemicals or vegetative matter) used to stabilize a streambank against erosion by providing protection and nutrients while vegetation becomes established. These agents, which may be in the form of liquids, emulsions, or slurries, are normally applied by mechanical broadcasters.

Overbank flow - Water movement over top bank either due to a rising stream stage or to inland surface-water runoff.

Oxbow - The abandoned bow-shaped or horseshoe-shaped reach of a former meander loop, that is left when the stream cuts a new shorter channel across the narrow neck between two closely approaching bends of the meander.

Pavement - Streambank surface covering, usually impermeable, designed to serve as protection against erosion. Common pavements used on streambanks are concrete, compacted asphalt, and soil-cement.

Peaked stone dike - Riprap placed parallel to the toe of a streambank (at the natural angle of repose of the stone) to prevent erosion of the toe and induce sediment deposition behind the dike.

Perennial stream - A channel that has continuous flow.

Phreatic line - The upper boundary of the seepage water surface landward of a streambank.

Pile - An elongated member, usually made of timber, concrete, or steel, that serves as a structural component of a river-training structure.

Piping - Removal of soil material through subsurface flow of seepage water that develops channels or "pipes" within the soil bank.

Point bar - The convex side of a bend that is built up due to sediment deposition.

Quarry-run stone - Natural material used for streambank protection as received from a quarry without regard to gradation requirements.

Rapid drawdown - Lowering the water against a bank more quickly than the bank can drain, which can leave the bank in an unstable condition.

Reach - A portion of a channel between any two points.

Refusal - Erosion-resistant material placed in a trench (excavated landward) at the upstream end of a revetment to prevent flanking.

Reinforced-earth bulkhead - A retaining structure consisting of vertical panels and attached to reinforcing elements embedded in compacted backfill for supporting a natural or artificial streambank (a specific type of retaining wall).

Reinforced revetment - A streambank protection method consisting of continuous stone toe-fill along the base of a bank slope with intermittent fillets of stone placed perpendicular to the toe and extending back into the natural bank.

Retaining wall - A vertical structure used to maintain an elevation differential between the water surface and top bank while at the same time preventing bank erosion and instability.

Retard - Structure placed parallel to a streambank to prevent erosive currents from attacking the bank.

Revetment - Cover of erosion-resistant material placed to protect a streambank.

Riparian - Pertaining to anything connected with or adjacent to the banks of a stream.

Riprap - See stone riprap.

River training structure - Any configuration constructed in a stream or placed on, adjacent to, or in the vicinity of a streambank that is intended to deflect currents, induce sediment deposition, induce scour, or in some other way alter the flow and sediment regimes of the stream.

Rock-and-wire mattress - A flat or cylindrical wire cage or basket filled with stone or other suitable material placed on a streambank or filter as protection against erosion.

Rubble - Rough, irregular fragments of random size placed on a streambank to retard erosion. The fragments may consist of broken concrete slabs, masonry, or other suitable refuse.

Runout - See discharge.

Sack revetment - Streambank protection consisting of sacks (e.g. burlap, paper, or nylon) filled with mortar, concrete, sand, stone, or other available material placed on a bank to serve as protection against erosion.

Sand - Soil material that can pass the No. 4 (4.76 mm) U. S. Standard Sieve and be retained on the No. 200 (0.075 mm) sieve.

Scour - Erosion due to flowing water; usually considered as being localized as opposed to general bed degradation.

Sediment load - The sediment carried through a channel by streamflow.

Sediment yield - The total sediment outflow from a drainage basin during a specific period of time. The outflow includes bed load as well as suspended load, and usually is expressed in terms of weight or volume per unit time.

Seepage - The slow movement of water through small cracks and pores of the bank material.

Sill - A structure built across the bed of a stream to prevent scour or head-cutting; see also grade-control structure.

Silt - Material passing No. 200 (0.074 mm) U. S. Standard Sieve that is nonplastic or very slightly plastic and exhibits little or no strength when air-dried (Unified Soil Classification System).

Sloughing - Shallow movement of a soil mass down a streambank as the result of an instability condition at or near the surface (also called slumping). Conditions leading to sloughing are: bed degradation, attack at the bank toe, rapid drawdown, and slope erosion to an angle greater than the angle of repose of the material.

Soil-cement - A designed mixture of soil and portland cement compacted at a proper water content to form a veneer or structure that can prevent streambank erosion.

Spur dike - See dike.

Stable channel - A condition that exists when a stream has developed just the right bed slope and cross section for its channel to transport the water and sediment delivered from the upstream watershed without any of the sediment being deposited or without any soil particles being removed from the bed or bank.

Stage - Water-surface elevation of a stream with respect to a reference elevation.

Stone riprap - Natural cobbles, boulders, or rock dumped or placed on a streambank or filter as protection against erosion.

Streambank erosion - Removal of soil particles or a mass of particles from a bank surface due primarily to water action. Other factors such as weathering, ice and debris abrasion, chemical reactions, and land-use changes may also directly or indirectly lead to streambank erosion.

Streambank failure - Collapse of a bank due to an instability condition.

Streambank protection - Any technique used to prevent erosion or failure of a streambank.

Suspended-sediment load - That part of a stream's total sediment load which is transported within the body of fluid and has very little contact with the bed.

Synthetic mattress, matting, or tubing - A grout- or sand-filled, manufactured, semiflexible casing placed on a streambank to prevent erosion.

Tetrahedron - Component of river-training works made of six steel or concrete struts fabricated in the shape of a pyramid.

Tetrapod - Bank-protection component of precast concrete consisting of four legs joined at a central joint, with each leg making an angle of 109.5 deg with the other three.

Thalweg - The line extending down a channel that follows the lowest elevation of the bed.

Tieback - Structure placed between revetment and bank to prevent flanking.

Timber or brush mattress - A revetment made of brush, poles, logs, or lumber interwoven or otherwise lashed together. The completed mattress is then placed on the bank of a stream and weighted with ballast.

Toe - That portion of a stream cross section where the lower bank terminates and the channel bottom or the opposite lower bank begins.

Toe-fill - Break in slope between the bank and the overbank area.

Tractive force - The drag on a streambank caused by passing water which tends to pull soil particles along with the streamflow.

Trench-fill revetment - Stone, concrete, or masonry material placed in a trench dug behind and parallel to an eroding streambank. When the erosive action of the stream reaches the trench, the material placed in the trench armors the bank and thus retards further erosion.

Turbulence - Motion of fluids in which local velocities and pressures fluctuate irregularly in a random manner as opposed to laminar flow where all particles of the fluid move in distinct and separate lines.

Upper bank - The portion of a streambank having an elevation greater than the mean water level of the stream.

Vane dikes - Structures designed to direct streamflow away from an eroding bank line, but permitting limited amounts of both water and sediment to pass landward of the structure.

Vegetation - Woody or nonwoody plants used to stabilize a streambank and retard erosion.

Velocity (of water in a stream) - The speed that water travels in a given direction; expressed as a distance traveled during an interval of time.

Watershed - See drainage basin.

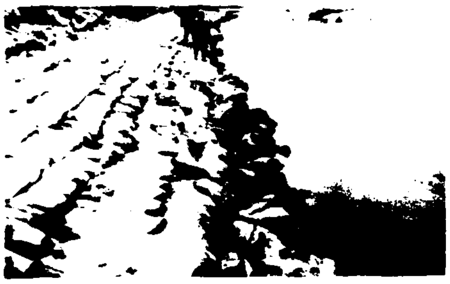
Wave attack - Impact of waves on a streambank.

Windrow revetment - A row of stone (called a windrow) placed on top bank landward of an eroding streambank. As erosion continues the windrow is eventually undercut, launching the stone downslope, thus armoring the bank face.

**THE STREAMBANK
EROSION CONTROL EVALUATION
AND
DEMONSTRATION ACT OF 1974**

SECTION 32, PUBLIC LAW 93-251

US Army Corps
of Engineers


Sand-Cement Sack Revetment


Jack-Type Retards


Willow And Tire Revetment


Tire-Filled Cribs

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